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DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS

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DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS

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FOREWORD

This report summarizes design studies of turbine generator units designed as part of an analytical comparison of cesium and potassium as working fluids for Rankine cycle space power plants. The work was conducted by the Oak Ridge National Laboratory for NASA under AEC Interagency Agreement 40-98-66, NASA Order W-12,353 under the technical management of A. P. Fraas of the Oak Ridge National Laboratory. Project management for NASA was performed by S. V. Manson of NASA Headquarters.

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DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS

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Abstract

The first phase of the study comparing cesium and potassium as working fluids for 300 kw electrical output power plants was concerned with a review of the literature and operating experience both with all sorts of small turbines and with rotating machinery in high temperature systems. From this review a basic set of design precepts was developed to provide a self-consistent set of bases for the study. The next phase of the work entailed a parametric study to determine the effects on turbine efficiency, size, and other key parameters of variations in the number of stages, the rpm, the turbine inlet and exhaust temperatures, and effects of various losses such as aerodynamic, seal leakage, moisture churning, and bleed-off for regenerative feed heating. On the basis of this work a two-stage and a three-stage cesium turbine and a five-stage and an eight-stage potassium turbine were chosen as reference designs for detailed analytical and layout studies. Layouts were prepared and then analyses were made of the major problems including creep stresses in the turbine rotors, temperature distribution and thermal stresses in the turbine rotors, the dynamics of the bearings and rotors, and moisture formation, deposition, and possible turbine bucket erosion. The results indicate that the two working fluids yield essentially the same overall thermal efficiency, but that cesium gives a lighter and simpler turbine-generator unit.

INTRODUCTION

A number of authorities have pointed out that the thermodynamic properties of cesium afford the turbine designer some degrees of freedom that are not available with potassium, and that these may make possible lighter, simpler, more reliable turbines. The problems involved have been examined by a number of organizations.[1-3] Some have concluded that there would be a major advantage to the use of cesium. The Oak Ridge National Laboratory was asked by NASA to undertake a comparative study of the two systems with the objective of highlighting the principal differences that result from the use of one fluid or the other, and the principal advantages and disadvantages of each from the standpoint of the design and development of the individual components and the complete integrated systems (AEC Interagency Agreement 40-98-66, NASA Order W-12,353).

This report summarizes the analytical and layout work on which the reference designs for the turbine-generator units were based. In view of the fact that there are over twenty independent design parameters that affect the performance of a turbine-generator, it is difficult indeed to establish an "optimum" design. The matter is rendered even more difficult by the fact that both fabricability and reliability must be considered, and the influence of the design parameters on these considerations are subtle and difficult to evaluate. Thus this study has been less concerned with the development of an "optimum" design than with a critical comparison of the influence of the choice of working fluid on the design and performance of the turbine with due consideration for reliability and fabricability.

By a fortunate coincidence, this study has been carried out almost concurrently with a roughly similar study of steam turbine generator units[4] carried out under the Terrestrial Low Power Reactor program of the AEC. The similarities and differences that have become apparent in the course of the design studies for the wide variety of conditions considered have helped greatly to place the many different problems in perspective.

SUMMARY

This study indicates that there is no difference between cesium and potassium in the aerodynamic performance obtainable from a well-proportioned turbine. The optimum operating speed for the 300 kw cesium turbines appears to be about 18,000 rpm as compared with 24,000 rpm for potassium (this stems from the higher molecular weight of the cesium). The greater density of the cesium vapor leads to the somewhat smaller turbine rotor diameters for cesium.

Thermodynamic cycle analyses indicate that there is no difference in the overall thermodynamic cycle efficiency for operation between a

given set of temperature limits using a simple Rankine cycle. If regenerative feed heating is employed, the thermodynamic calculations show a small advantage for cesium stemming from the greater specific heat of the liquid. The Mollier diagrams also indicate a somewhat higher moisture content for an isentropic expansion of potassium as compared to cesium between the same temperature limits. This leads to somewhat higher moisture churning losses for potassium than for cesium. The higher molecular weight of cesium also leads to lower sonic velocities and hence lower leakage losses through labyrinth seals. The combined effects of these factors lead to a loss of about one point in cycle efficiency if the number of stages is the same. The difference can be balanced by reducing the exit losses by using more stages in the potassium turbines.

An investigation of the turbine bucket erosion problem indicates that the threshold for erosion would be at a higher tip speed for cesium than for potassium, and the threshold for either would be higher than for steam. In the reference design turbines there should be no difficulty with erosion caused by droplets dribbling from the stator blades, but it will probably be necessary to provide for moisture removal between stages in both the cesium and potassium turbines to avoid erosion caused by large drops that would otherwise be torn from the relatively thick film of liquid that would move along the wall of the outer casing.

The higher molecular weight of cesium gives a greater temperature ratio per stage without excessive tip speeds so that close to a maximum efficiency is obtainable with a three-stage cesium turbine as compared to a seven- or eight-stage potassium turbine. If approximately one point in cycle efficiency is sacrificed to reduce the number of stages, it is possible to use either a two-stage cesium turbine or a five-stage potassium turbine and obtain the same efficiency. Thus for a given cycle efficiency the cesium turbines are substantially smaller and lighter than their potassium counterparts.

Using the parametric study as a basis, both a two-stage and a three-stage cesium turbine and both a five-stage and an eight-stage potassium turbine were chosen for reference design purposes. Both two-bearing and four-bearing layouts were investigated for the three-stage cesium and the five-stage potassium turbines. The two-stage cesium turbine was designed as a two-bearing machine while the eight-stage potassium was made a four-bearing machine. Of these, the two-bearing, three-stage cesium turbine and the four-bearing, eight-stage potassium turbine-generator units (having weights of 810 lb and 1230 lb, respectively) were chosen for use in the overall system layout and integration studies.

A creep stress analysis of the rotors indicates that creep will not be a problem in the first stage rotors of the cesium turbines but it would be a serious problem in the original reference designs for the potassium turbines.

If this condition were alleviated by reducing the turbine inlet temperature, the loss in overall cycle efficiency would run about one point. However, it appears reasonable to hold the turbine inlet temperature at 2150°F and reduce the turbine wheel stresses sufficiently to avoid difficulties with the creep by reducing the first-stage rotor diameter about 22%. The resulting deviation from optimum aerodynamic proportions gives a loss of about 3% in the efficiency of the first stage and an overall loss in cycle efficiency of about two-tenths of a point.

A study of the bearing and rotor dynamics indicates that, for five of the six reference designs, the third critical speed can be placed well above the design speed and the damping in the bearings should be adequate to limit the amplitude of journal gyrations in the bearings to moderate values in passing through the first two critical speeds which are rigid body critical speeds. The sixth reference design, the five-stage potassium turbine in which three-stages would be overhung at one end of the generator shaft and two stages overhung at the other, gave rather large amplitudes of journal gyrations, and hence appeared to be an undesirable choice for a development program. In general, the orbit amplitudes were lower for cesium than for potassium.

BASIC DESIGN CONSIDERATIONS

A review of the literature and extensive discussions with many experts in the field served to delineate the basic design considerations for the work on the turbine-generator units. These are summarized and some of the subtleties are discussed in this section to show the rationale behind the boundary conditions established first for the parametric studies and then for the layout and analytical design work.

Generator

The size and weight of the generator and much of the equipment in the electric power distribution system, particularly motors and transformers, falls off fairly rapidly with an increase in frequency up to 1000 to 2000 cps, whereas line losses associated with inductive effects increase fairly rapidly with frequency above about 2000 or 3000 cps. Thus for minimum weight of the electrical system, the generator frequency should be somewhere between 1000 and 3000 cps. There is very little equipment in the way of motors, transformers, switchgear, etc., that has been designed and built for frequencies above 400 cps, so that higher frequencies will require the development of much new equipment. The weight savings possible by going to 1200 cps as opposed to 400 cps have led NASA to favor the development of the 1200 cps equipment, hence this study was based on 1200 cps for the reference designs.

There seems to be general agreement that the most reliable type of generator for power outputs of more than about 100 kw is an inductor-alternator. Four or more poles must be used in this type of machine because the rotating magnetic couple associated with a two-pole machine would lead to severe vibration and bearing problems.

The choice of 1200 cps for the generator gives quite a range of possible speeds, that is, a four-pole machine would operate at 36,000 rpm, a six-pole machine would operate at 24,000 rpm, an eight-pole machine would operate at 18,000 rpm, a ten-pole machine would operate at 14,400 rpm, and a twelve-pole machine would operate at 12,000 rpm, thus providing considerable latitude in the choice of turbine rpm. This approach makes it possible to take advantage of the high speed potential of the potassium and cesium vapor turbines, although the advantage of the 1200 cps generator over a 400 cps is not as great for cesium as for potassium.

Possible reference designs for the generator were discussed with NASA personnel in connection with the investigation of the rotor and bearing dynamics problem. It was agreed that the SNAP-50 generator would be used as the reference design machine, and that both a four-bearing and a two-bearing configuration for the complete turbine-generator unit would be examined. (In a four-bearing machine, the turbine would be coupled to the generator with a quill shaft; in the two-bearing machine, the turbine would be overhung out-board of the bearing at one or both ends of the generator rotor.). In view of the difference between the 1200 cps generator output frequency specified by NASA for this study and the 3200 cps for which the SNAP-50 generator was designed, it seemed best to check with Westinghouse on the effects of the change in design frequency on the rotor proportions. The problems were discussed with Westinghouse in light of their recent work on the problem under AEC Contract,[5] and the generator proportions defined in Table 1 were taken from Refs. 5 and 6.

Turbines

The number of stages, size, weight, and cost of a turbine for a cesium or potassium Rankine cycle can be reduced as the rotor tip speed is increased up to the range of 1000 ft/sec to 1500 ft/sec. At the higher speeds, compressibility losses, rotor stresses, and bucket erosion by moisture become progressively more likely to induce substantial losses. Thus the combination of roughly 1000 ft/sec tip speed required for good turbine design and the 12,000 to 24,000 shaft rpm dictated by generator design considerations leads to rotor diameters of approximately 10 in. if the blading design is compromised between that for maximum efficiency and that for maximum work per stage. (That is, the tip speed should be made somewhat less than about half the tangential velocity at the nozzle exit.)

Since efficiency is a less important consideration than reliability in space power plants than in central stations, it is possible to reduce the size and bearing loads, simplify the design, and reduce the cost of the turbine by reducing the number of stages through the use of a relatively high pressure ratio per stage with simple impulse turbine blading.

Design for Reliability

In view of the high importance of reliability, it seems in order to give particular attention to the bearings. The radial loads will depend mainly on the weight of the rotor per square inch of bearing area. Experience indicates that, to avoid scuffing during startup, it is desirable to keep the bearing loads to about 30 psi or less. As discussed in the previous section, high speeds will be required for good efficiency, light weight, and compactness, hence the bearings must be designed to avoid instability and whip. This implies the use of stepped pad, tilting pad, or similar bearings. The turbine should also be designed to keep the thrust loads low — if possible, negligible. Thus the aerodynamic design of the turbine should be such that the axial piston pressure loads on the rotor will be balanced, which implies that impulse blading should be used. Impulse blading will yield a somewhat lower efficiency than reaction blading, particularly for the last stage, but this loss in efficiency would be offset in large measure by greatly reduced frictional power losses in the thrust bearing. These commonly run 5% or more in a high speed reaction turbine of this type.

It may be desirable to reverse the flow or go to double flow in the last stage of the larger turbines so that the last stage will be at the end of the rotor adjacent to the first stage. This would permit balancing of small amounts of reaction in the longer blades of the last stages, and has the additional advantage that, if bearings are used at both ends of the rotor, neither bearing will be exposed to the high-temperature vapor entering the turbine.

The reversed flow arrangement introduces complications, and will reduce the turbine efficiency somewhat, but it has the advantage that, if a journal bearing is used at either end of the rotor, the structure joining the two bearings can be held at a uniform temperature so that good alignment can be maintained. Some designs, for example, the AiResearch SNAP-50 turbines, have included provisions for cooling the bearings so that they would be held at a substantially lower temperature than either the inlet or exhaust vapor. This approach has the disadvantages that thermal distortion seems more likely and either a good deal of heat will be lost to the bearing coolant as a consequence of condensation of vapor on the bearing mount, or a very close clearance labyrinth seal must be employed to inhibit leakage of vapor into the cavity surrounding the bearing. Such a close clearance labyrinth seal would be likely to detract from the reliability of the machine.

Moisture Removal

It is advantageous to employ a regenerative feed heater in the system to improve the thermal efficiency of the cycle and thus reduce the size of both the reactor and the radiator - both of which represent major size, weight, and cost items. Feed heating also has the advantages that it should reduce thermal stresses at the boiler inlet, improve flow stability in the boiler, and provide a convenient means for bleeding off liquid and vapor between stages to keep down the moisture content and thus reduce the losses in turbine efficiency associated with liquid impingement on the rotor blades as well as possible turbine bucket erosion.

Moisture deposition on turbine rotor and stator blades leads to large momentum losses as liquid is thrown off the rotor blade tips or dribbles off the stator blades into the rotor and is accelerated to the rotor tip speed. These liquid churning losses commonly run from about 0.5% to 1.5 % (Ref. 7-10) in turbine efficiency for each 1% of moisture in the vapor stream. The most effective moisture removal devices in common use rarely take out more than 25% of the moisture.[11] However, there is reason to believe that the use of interstage bleeds, possibly coupled with porous stator blades, can be vented to a regenerative feed heater to make possible a substantial reduction in these losses.

Turbine bucket erosion is a function of many parameters, particularly turbine tip speed. Current practice indicates that, with proper design for moisture removal and with stellite inserts, it is possible to keep steam turbine bucket erosion within acceptable limits for tip speeds as high as 1850 ft/sec. Analyses in a companion report[9] indicate that for cesium or potassium the threshold for erosion is higher than for water.

The thermodynamic analyses indicate that vapor can be bled off between stages to aid in the removal of moisture and at the same time used in a regenerative feed heater to improve the cycle efficiency as much as 18%. This makes possible a corresponding decrease in the size and weight at the radiator as well as appreciable reductions in the size and weight of the reactor and shield assembly. Interstage bleed-off in this fashion also improves the proporti of the turbine in that it increases the height of the first stage ..ues (which tend to be too short) and reduces both the diameter and the blade height in the last stage. In view of these major advantages, it was decided that the reference design turbines and systems should include interstage bleeds and regenerative feed heating.

Heat losses as a consequence of conduction from one stator stage to the next should be reduced through the use of heat dams. These might be formed by gaps filled with vapor which – for either potassium or cesium – has a thermal conductivity of less than 0.01 Btu/hr·ft·°F.

Design Precepts

The design precepts and boundary conditions on which the turbine design work was based are summarized in Table 2. Many of these are implicit in the above discussion. In general, these stem from operating experience at ORNL coupled with an extensive survey covered in a companion report.[12] Others, while not mentioned above, are sufficiently straightforward that discussion seemed unnecessary. Still others required special treatment in the analyses, and it seemed best to combine the general discussions of these items with the detailed explanation of the way in which the calculations were handled in this report, hence these are discussed in later sections.

ANALYTICAL DESIGN PROCEDURE

There are so many variables involved in the design of a turbine and so many boundary conditions must be met that it is difficult to see how to arrive at a nearly optimum design, especially if allowances are made for losses associated with seal leakage, regenerative feed heating, and moisture churning by the rotor. After a number of false tries, a procedure was worked out for carrying out the thermodynamic and aerodynamic calculations including these factors in a systematic fashion to yield the proportions and performance of a turbine that will meet the boundary conditions of Table 2 and yet give close to the maximum efficiency obtainable with any given number of stages. This procedure utilizes the analytical approach presented by Baljé in Refs. 15 and 16. The bases for it are summarized in Table 3. The symbols used are defined in the table of nomenclature at the end of this report. The symbols used by Baljé served as a point of departure in setting up this table, but a number of changes were made because other aspects of turbine design are treated elsewhere in the report, and an effort was made to employ a single set of symbols for the entire report insofar as this was possible.

Thermodynamic Analysis

The thermodynamic calculations were carried out using the thermodynamic data compiled by the Naval Research Laboratory.[17,18] The NRL data for cesium were used to draw a larger scale chart with constant temperature lines at 25°F intervals instead of the 100°F intervals of the NRL chart to facilitate a more precise reading of the chart scales. This chart is included as Fig. 46.

Simple Idealized Cycles

A number of simple idealized cycle calculations were carried out partly to provide a basis for appraising the accuracy with which the Mollier diagrams might be read, partly to give some insight as to the possibility of accumulations of errors stemming from uncertainties in the physical properties used to construct the Mollier diagrams, and partly to provide a simple means of checking the calculations for the multi-stage turbines. These calculations are summarized in Table 4, and the results are plotted in Figs. 1 through 3. Note in Fig. 1 that the calculated points for cesium and potassium scatter indiscriminately about the curves for the two different turbine inlet temperatures considered so that, at any given turbine inlet temperature, there is no appreciable difference in the thermal efficiency of the ideal Rankine cycle between cesium and potassium. This is not surprising, but it is interesting that there is apparently no accumulation of errors that would lead to an apparent difference for calculations made using the charts employed in the study. Note, too, that the scatter of the points relative to the mean curves amounts to less than 0.4 of a percentage point, a surprisingly small amount in view of the fact that each cycle efficiency represents the ratio of two differences in enthalpies read from the Mollier diagrams.

Figure 2 shows an interesting comparison of the calculated thermal efficiencies for the 2150°F turbine inlet temperature idealized Rankine cycles of Fig. 1, the ideal Carnot cycle, and a series of approximations to the actual cycle. In this instance, the line drawn through the points calculated for the ideal, simple, Rankine cycle was actually drawn as a line for cycles having a thermal efficiency 89% that of the ideal Carnot cycle efficiency. Note that this appears to be as good a mean line through the points from Table 4 as one could draw. Figure 3 shows a similar chart for a turbine inlet temperature of 2000°F. As a matter of interest, other lines have been drawn on the same charts to show the results of aerodynamic and thermodynamic calculations made in later sections. These curves show the effects on the overall thermal efficiency of allowances for regenerative feed heating and the principal aerodynamic, moisture churning, and seal-leakage losses.

Multi-Stage Calculations

A series of thermodynamic calculations was carried out for multistage turbines to provide the basis for the aerodynamic claculations. To facilitate the calculations, the temperature drop per stage was held constant throughout any given turbine except that the turbine inlet temperature to each stage was rounded off to the nearest 10°F and the slightly greater temperature drops stemming from this were introduced at the low temperature end. The pressure, specific volume, and liquid enthalpy data were taken from tables in the NRL reports.[17,18] Points in the expansion were obtained from the Mollier diagrams by conventional techniques. The reheating effects associated with the aerodynamic losses in each stage were approximated by assuming a stage efficiency of 0.75 for each stage. While the thermodynamic calculations could be iterated after obtaining a better value for the efficiency from the aerodynamic calculations, the constant pressure lines are so nearly parallel on the Mollier diagram that an approximation is usually good enough so that, for a parametric study such as this, the thermodynamic calculations need not be iterated. (A second iteration was made for the reference design turbines covered in a later section.) The turbine nozzle efficiency will be so close to 100% that the nozzle exit velocity may be taken as being the ideal value. Allowances for regenerative feed heating were made by assuming a regenerative feed heater having a thermal effectiveness of 80% with an inter-stage bleed-off between each pair of turbine stages supplying the requisite vapor to the corresponding stage of the feed heater. The vapor bleed-off requirements for this purpose were calculated and tabulated together with the resulting net vapor flow fraction into each stage. The calculations are tabulated in Tables 5 and 6. The circled number at the head of each column in Tables 5 and 6 was used as a symbol to indicate steps in the calculations in subsequent columns and in subsequent tables for the aerodynamic calculations.

Aerodynamic Calculations Using the Baljé Charts

A number of different techniques for carrying out the turbine aerodynamic design calculations were considered. Of these, the most suitable for the purposes of this study appeared to be one based on the use of the analyses and charts presented by Baljé in Ref. 15 and reproduced here as Figs. 4 and 5. These charts were developed by Baljé from a very clever analysis in which he reduced the many different turbine design parameters and basic relations to a few equations. Inasmuch as practical problems ordinarily are such that these equations cannot be solved explicitly, Baljé devised a set of charts to facilitate their solution. The charts make it possible to find the best combination of parameters for the case at hand, that is, the designer can choose the appropriate chart for the type of turbine stage at hand and find the point on the chart that most nearly satisfies the conditions that he wishes to meet and, once he becomes familiar with the charts, can easily see the effects of changes in design conditions. It should be noted that the basic relations used by Baljé in his derivation are widely accepted as fundamentally sound, but that it is necessary in using them to employ such quantities as the aerodynamic characteristics of airfoils that are normally derived from tests. In preparing his charts, Baljé derived the necessary constants from a comprehensive set of test data obtained with representative turbines. Since these were not fully optimized, developments through the years should bring about some improvements. However, it is believed that the basic relations are valid so that any improvement will benefit one working fluid as much as another. Thus, for the purposes of this study, a valid comparison of cesium and potassium turbines can be made using the charts. If, for example, developments in aerodynamics should make possible a general increase in efficiency (which would in effect dilate the constant efficiency contour lines of the chart of Fig. 4*), this improvement in efficiency would apply equally well to cesium and potassium provided that, in both instances, the turbine designer made use of the available degrees of freedom to take advantage of the improvement. Care has been exercised in this study to do this, and nothing has come up to suggest that the degrees of freedom are not sufficient to permit achieving essentially the same aerodynamic efficiencies.

The charts from Ref. 15 presented in Figs. 4 and 5 depend on the fact that the 25 independent parameters indicated in Table 7 can be reduced to a few dimensionless parameters. The balance of the parameters have substantially smaller effects on turbine performance, and their effects can be taken into consideration by applying corrections to the proportions derived from Figs. 4 and 5. Some useful cross-plots of the data

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*A recent report of Baljé presents a refinement of the analysis of Ref. 15 applicable to reaction turbines.[16] This shows that higher efficiencies are possible through proper selection of the pitch-chord and blade height-chord ratios. These refinements were not included in the subject study because the new data are for reaction rather than impulse turbines.

in Figs. 4 and 5 for the maximum efficiency obtainable at any given value of N_s are presented in Fig. 6.

Effects of h/D

A detailed study of Baljé's derivation and its use as the basis for a computer program led to somewhat different values of the ratio of blade height to wheel diameter (h/D) for maximum efficiency than are given by either the h/D lines in Fig. 4 or Eq. (31) of Baljé's analysis. The matter was discussed with Baljé, and he pointed out that the turbine efficiency is insensitive to the h/D ratio over a wide range of h/D ratios. A computing machine program was developed to solve Baljé's equations on which the charts of Figs. 4 and 5 were based. A typical set of solutions gave the curves of Fig. 7 for the turbine efficiency as a function of h/D for constant values of D_s and N_s. Also plotted in Fig. 7 are curves for α_2 and β_2, that is, the inlet nozzle angle and the blade rotor entrance angle. Note that the efficiency is surprisingly insensitive to h/D, particularly for intermediate stages where the efficiency based on the total pressure at the stage exit is more significant than the static efficiency. However, the large kinetic energy losses in efficiency in the last stage for small blade heights coupled with the diffuser losses to be expected with large amounts of channel divergence favor selection of the larger h/D ratios even in the intermediate stages.

Seal Leakage

Some fraction of the vapor stream tends to bypass each stage by flowing through the labyrinth seal between the stator and the rotor. With the impulse turbine design contemplated, the pressure differential across each of these labyrinth seals will be equal to the total pressure drop for the stage. In addition, leakage from the first-stage rotor (which will be at the static pressure of the first-stage discharge nozzle) back toward the adjacent bearing will represent a substantial loss. The effects of this loss can be reduced through the use of a series of intermediate bleed points to conduct a portion of the leakage to appropriate points in the regenerative feed heater. Of course, it is necessary to make sure that the amount of vapor bled off for this purpose does not exceed the requirements of the feed heater, but this has been found not to be a problem for the turbine proportions under consideration in this study.

In estimating the magnitude of the seal leakage losses, the work of Egli was employed.[13] While this was based on work with steam, it is also readily applicable to potassium and cesium vapor. Egli's relation for the leakage through a labyrinth of n lands is

$$G = A\alpha\Phi\gamma\sqrt{\frac{gp_o}{v_o}}$$

where

A = orifice area, ft^2
G = flow rate, lb/sec
g = acceleration of gravity, ft/sec^2
n = number of lands
p_n = downstream pressure, lb/ft^2 abs.
p_o = upstream pressure, lb/ft^2 abs.
v_o = upstream specific volume, ft^3/lb
α = orifice coefficient
Φ = labyrinth coefficient (a function of n and p_n/p_o)
γ = coefficient dependent on geometry

Egli determined the value of $\alpha\Phi$ experimentally with steam for a wide range of seal proportions and pressure ratios, and his experimental results checked closely with analytically derived values. The effects of both the number of lands in the seal and the ratio of the upstream and downstream pressures are summarized in Fig. 8.

A major factor influencing the magnitude of the seal leakage is the radial clearance between the shaft and the lands of the labyrinth seal. Dodge[14] recommends a clearance of 0.0015 in. to 0.0025 in. for a 3.5-in. journal diameter, the value which preliminary layouts indicate will be appropriate. If an attempt is made to rationalize a clearance, it is evident that the diametral clearance in the bearings — about 0.003 in. — will be a major factor. In addition, some allowance must be made for the accumulation of tolerances affecting the concentricity of the casing with respect to the shaft, ovality of the casing, and distortion of the rotor. Experience with high-temperature pumps at ORNL indicates that the combined effects of these factors will be such as to require approximately an additional 0.002 in. of radial clearance. If the minimum clearance is to be 0.002 in. after allowance for these factors, the nominal overall radial clearance becomes about 0.0055 in. This is somewhat higher than the allowance recommended by Dodge, but it seems in order in view of the much higher temperature at which the machine will operate, and consequently the greater opportunity for differential thermal expansion and thermal distortion.

Preliminary estimates of the seal leakage losses indicate that these will run of the order of 5% for the turbines under consideration even with 12 lands in each seal. As a consequence, it seemed best for the purposes of this study to assume that each seal would employ twelve lands with no steps in diameter between lands (steps would cut the leakage by a factor of 2), and that the seal between the first-stage rotor and the adjacent bearing would consist of three or four sets of twelve lands each with intermediate bleed-offs to the regenerative feed heater. (The number of bleed-offs in the seal would correspond to the number of extraction points for multi-stage feed heating.) To facilitate the calculation of the amount of flow bypassing each stage, Fig. 9 was prepared to define the leakage rate through the labyrinth seals as a function of the upstream pressure. For 0.010-in.-thick lands on 0.050 in. centers, the values of α and γ taken from Egli's paper (Ref. 13) for construction of Fig. 9 were both unity, and values for Φ were taken from Fig. 8.

In calculating the aerodynamic performance of the turbine, the thermodynamic data of Tables 5 and 6 were used as a point of departure. Allowances for the flow bypass through the labyrinth seals was made on the basis of the chart of Fig. 9 with a correction to allow for the value of the leakage bled from intermediate stages in the seal between the first-stage rotor and the adjacent bearing. (In effect this would reduce the amount of interstage bleeding required for feed heating — for which allowances have already been made in Tables 5 and 6.) These calculations are summarized in Table 8.

It should be noted that the preceding paragraph implies a four-bearing machine, but the same reasoning also applies to a two-bearing machine with the turbine wheels overhung from the generator rotor with all of the stages at one end of the generator. This comes about because a seal is required between the first stage rotor and the end of the shaft to balance the piston pressure forces on the rotor shaft at the high pressure end of the turbine, as the pressure force would otherwise give an excessive axial thrust load. The region outboard of the seal should be vented to the low pressure end of the turbine so that the same pressure will act on both ends of the shaft. (For the cesium vapor turbine under consideration here, for example, without such a seal the axial thrust load arising from piston pressure forces would run around 2100 lb, a completely unacceptable thrust force.) If a two-bearing machine were employed with some stages at one end of the generator and some at the other, it would be possible to use two different journal diameters at the labyrinth seals and choose these to balance the piston forces at design conditions. Unfortunately, it is not possible to obtain a good balance throughout the load range, and large axial loads would occur under some conditions unless the seal arrangement used is similar to that postulated above.

The power losses associated with friction in labyrinth seals of the type used here are not large and were neglected in this study. The frictional losses in the type of seal required in the generator, however, are likely to be substantial if the pressure in the generator rotor cavity is to be kept to the low level desired to minimize windage losses. In view of the many uncertainties in the detail design of the generator, and since these losses are insensitive to turbine design parameters over the range of interest in this study, the shafts frictional losses in the bearings and seals were neglected.

Tip Clearance Losses

On the basis of steam and gas turbine experience, Baljé chose to prepare his charts on the basis that the clearance between the tips of the blades and the casing would be responsible for a loss which happens to be roughly equal to twice the ratio of the tip clearance to the blade height (Ref. 15, p. 89), and Baljé prepared the charts of Ref. 15 assuming a value of 0.02 for the ratio of tip clearance to blade height.

In attempting to rationalize a suitable tip clearance for this study, the approach employed in the previous section on labyrinth seal leakage appears in order except that a somewhat greater distortion must be anticipated at the greater diameter of the rotor tip, and this implies that a radial clearance of the order of at least 0.01 in. should be provided. In addition, some allowance must be made, particularly in the higher temperature stages, for growth of the rotor as a consequence of creep. Since this is difficult to specify, it seemed desirable to proceed with the aerodynamic calculations using an additional allowance of 0.01 in. for this factor with the intent that a correction could be superimposed on the calculations as a final step if such a correction appears to be in order. On this basis a tip clearance of 0.020 in. appears reasonable; this would be the same as that assumed in the construction of Baljé's charts provided that the blade height is 1 in. It can be seen intuitively that a flat assumption of the clearance of 0.020 in. throughout the turbine will probably give a value for the ratio of the tip clearance to the blade height that would be greater than 0.02 for the earlier stages and less than 0.02 for the latter stages. Thus the estimates of stage efficiency using Baljé's charts will probably be on the high side for the early stages and perhaps on the low side for the last stages where the long blades may permit a small reduction in the tip leakage loss.

Calculation Techniques

Both the computing machine program referred to in the discussion of the effects of h/D and a hand calculation technique were employed independently to investigate the effects of design conditions on the turbine proportions yielded by application of Baljé's approach to the optimization for maximum turbine efficiency within the framework of the design precepts presented in the previous section. The detailed procedures used are presented in the two following sections. Each approach was found to have its advantages and disadvantages; for example, the hand calculation procedure lent itself better to the investigation of the detailed effects of the various types of loss, while the machine program required only about one-half a manhour per case as compared to about four manhours for the hand calculations. However, no good way was found for programming subroutines for the computing machine to investigate the effects of such factors as bleed-off for regenerative feed heating and seal leakage, hence these effects had to be investigated by hand calculations only. As will be shown later, the results of the two independent approaches where both could be used provided a valuable check on each other.

Aerodynamic Calculation Procedure Using a Desk Calculator

Baljé's analysis shows that the efficiency of a turbine stage is completely determined by the specific speed, N_s, and the specific diameter, D_s. Since $N_s = N\, V_3^{1/2}/H_{ad}^{3/4}$ and $D_s = D\, V_3^{1/2}/H_{ad}^{3/4}$, and since N, V_3, and H_{ad} are defined for any particular stage and vapor weight flow rate by values given in Tables 5 and 6, the problem is reduced to one of determining the rotor diameter that will give as high an efficiency as possible. It happens that a simple way of determining this without attempting a complex interpolation is provided by cross plotting data from Baljé's charts of Figs. 4 and 5 to give Fig. 6. Inasmuch as a major boundary condition is that the number of stages be minimized (i.e., the head per stage be a maximum), the minimum value of N_s for any given efficiency represents a point on the curve defining the desired relationships. Thus, points for both efficiency and D_s were plotted on Fig. 6 as a function of N_s for each of the constant efficiency curves of Baljé's charts in Figs. 4 and 5 to define curves for the maximum stage efficiency obtainable. Note that two curves are given, one based on the total and one on the static pressure at the stage exit. The former curve can be used for all but the last stage, while the latter should be used for the last stage because the velocity energy in the stream leaving the last stage of a turbine is not recoverable. Curves for H_{ad}, D, and the tip speed U for 24,000 rpm and some typical values of V_3 were added on the same sheet to give an insight into the relations involved.

Table 9 presents the series of operating conditions for which parametric study calculations were made. These combinations of conditions were chosen to provide as much insight as possible into the effects of the design conditions on turbine proportions and cycle efficiency. The calculations themselves are presented in Tables 10 and 11, and the steps in the calculational procedure are summarized in Table 12.

The turbine output, and hence the efficiency, is reduced by the loss of mass flow through the turbine buckets as a consequence of flow bypassing through the labyrinth seals as well as bleed-off for moisture removal and regenerative feed heating. These items can be estimated and the net flow fraction passing through each rotor stage determined. The loss associated with churning of the droplets impinging on the rotor blades can also be estimated assuming that it will run 1.25% per 1% of moisture. The work input to each stage of the turbine can then be calculated, and the values assumed to give the total work output of the turbine per pound of vapor entering the first stage. This value divided by the heat added in the boiler (from Table 5 or 6) gives the gross cycle efficiency.

The ideal work input to the feed pump is approximately 2 Btu/lb for potassium. If a free-turbine-driven feed pump is supplied with vapor bled from the inlet to the last stage of the main turbine, the overall efficiency for the turbine and pump unit would be about 25%. This would give a value of about 8 Btu/lb for the feed pump work, or about 1% of the heat input to the cycle. The value for cesium would be similar. (Bleed-off for the feed pump turbine would reduce the vapor flow through the last stage of the turbine by roughly 10%, but this effect was not included in the calculations of Tables 5 and 6.) The generator efficiency will run about 92%. Miscellaneous heat losses to radiation, etc., will run about 1%. Thus, the net thermal efficiency of the plant will run about 90% of the gross cycle efficiency. The net electrical power output is given by the product of the vapor flow rate, the boiler heat input per pound of vapor, the net thermal efficiency, and the ratio 3600/3413 for conversion of units.

Inspection of Tables 5 and 6 and further calculations showed that in virtually all cases the relative velocity of the vapor entering the turbine buckets was below sonic, and hence no Mach number correction was required except for the single stage cesium turbine.

Aerodynamic Calculations Using a Computer Program

In carrying out the calculations outlined in the previous section it became evident that appreciable errors might be introduced by interpolation between the lines of the complex networks of the Baljé charts. To avoid such errors a computing machine program was prepared to solve the equations on which Baljé based his charts,[15] and thus a more accurate set of results could be obtained for turbines proportioned to minimize the aerodynamic losses. It proved very difficult to include the effects of seal leakage and regenerative feed heating in this program, however. In view of these difficulties and the good correlation obtained between the results obtained from the charts and those obtained from the computer program, the computing machine calculational work was limited to an investigation of the aerodynamic and moisture churning losses, but a wider range of combinations of rpm, number of stages, and turbine inlet and exhaust conditions was investigated. These included some single stage cesium turbines in which the relative Mach numbers entering the blades exceeded 1.1 so that additional hand corrections for compressibility losses were in order and were applied in obtaining the overall cycle efficiency (although they were not included in the "overall turbine efficiency" yielded by the machine program).

Machine Calculation Procedure. The velocity diagram calculations were based upon a pitch-line procedure similar to the aforementioned Baljé method.[15] The following salient differences should be noted:

a) The nozzle coefficient was assumed to be given by

$$\psi_n = 0.9488 + 0.0131\ \epsilon_s - 0.0867/\epsilon_s$$

where

$\epsilon_s = \alpha_1 + \alpha_2$ (angles in radians)

b) The rotor velocity coefficient was assumed as relation (27) in Ref. 15.

c) Axial inlet and discharge were assumed for each stage and $\alpha_2 \geq 15°$ whichever gave the maximum total-to-total efficiency.

d) The moisture correction was assumed to be given by

$$\Delta\eta = 4(1 - q_2)(u/C_0)^{7/4}$$

where q_2 is the leaving nozzle quality (which is nearly equal to the quality q_3 leaving the stage).

e) For the cesium turbines, an entering velocity of 300 ft/sec was assumed, while 500 ft/sec was assumed for the potassium turbine designs.

With the above assumptions, the calculations were performed by dividing the isentropic static enthalpy into equal stage increments, and the total stage efficiency maximized on α_2. This gave all the pertinent variables directly for an assumed weight flow. The weight flow was then matched for the specific turbine output. Table 13 gives the pitch line velocity diagrams for cesium, while Table 14 shows the results of similar calculations for potassium. The detailed steps in the program were as follows:

1. The entering velocity was taken as axial – 300 ft/sec for cesium and 500 ft/sec for potassium.

2. The nozzle coefficient ψ_n:

$$\psi_n = .9488 + 0.0131\ \epsilon_s - 0.0867/\epsilon_s$$

where

$\epsilon_s = \alpha_1 + \alpha_2$ (not stator deflection)(angles in radians)

3. Rotor velocity coefficient ψ_R:

$$\psi_R = \left[1 - 0.228\left(1 - \frac{2\beta_2}{\pi}\right)^3\right]\left[1 - .06\ C/h\right]$$

4.

$$C/h = 4\left(\frac{a^*}{D}\right)\cos\beta_2/(h/D)$$

with $a^*/D = 0.015$.

5. Use either $\alpha_2 \geq 15°$ or $\alpha_3 \leq 90°$ which ever gives the greater efficiency.

6. The change in efficiency due to moisture was calculated using the outlet quality since the quality entering the rotor will be quite close to this value. The equation used is:

$$\Delta\eta = 4(1 - Q_{out})(U/C_o)^{7/4} .$$

This fits Escher-Wyss data cited by Csanady, (Ref. 10, p. 347) presented here in Fig. 10. Note that the moisture churning losses are greater in reaction turbines, and increase as the degree of reaction increases.

7. The turbine rotor Reynolds number based on hydraulic diameter = 100,000. This affects only the disc power since the velocity coefficients do not change much above 100,000.

RESULTS OF PARAMETRIC CALCULATIONS

The objective of the parametric calculations was not so much to yield a highly optimized pair of reference designs for cesium and potassium turbines, but rather to show the sensitivity of the major geometric and performance parameters to variations in design conditions for nearly optimum combinations of design parameters.

Effects of the Number of Stages on Turbine Efficiency

A good insight into the effects of the number of stages on the size and efficiency of potassium and cesium turbines is given by Fig. 11. This set of calculations was carried out with the computing machine program with all the losses included by Baljé in Ref. 15, but with no provisions for regenerative feed heating or seal leakage. Note that the cycle efficiency increases very little with the number of stages beyond three stages for cesium or beyond five stages for potassium. This implies that these three-stage and five-stage units should be used for reference design purposes, since it is worthwhile to accept a small loss in efficiency to reduce the number of stages and thus ease the rotor dynamics problems and reduce the turbine size and weight.

Figure 12 shows the effects of the number of stages on the cycle efficiency and other parameters as determined by the hand calculations of Tables 10 and 11 which include allowances for both bypass leakage through labyrinth seals and regenerative feed heating. In this instance, the overall cycle efficiency has been plotted rather than the gross cycle efficiency because of the complex effects of regenerative feed heating. Note that again the three-stage cesium and five-stage potassium units appear to represent well-proportioned designs.

An examination of the data in Tables 5, 6, 10, and 11 discloses that the principal factor responsible for the increase in efficiency with the number of stages is the kinetic energy loss in the last stage; this becomes a progressively smaller fraction of the total head across the turbine as the number of stages is increased. It can also be seen from Fig. 12 that reducing the number of stages below three for cesium and five for potassium would lead to relative Mach numbers greater than 0.8 at the inlet to the turbine buckets, so that additional losses caused by compressibility effects might begin to become important.

Effects of Design RPM

Inspection of Table 5 together with Fig. 6 indicates that 24,000 rpm tends to give a rather high specific speed for cesium, and that there may be an advantage to employing a lower speed. Figures 13 and 14 show the effects of design rpm and number of stages on the turbine size, turbine bucket inlet Mach number, and the overall cycle thermal efficiency with allowances for aerodynamic, moisture, and seal-leakage losses as well as regenerative feed heating. These curves show that there is some advantage to the use of 18,000 rpm for the cesium turbine, and that 24,000 rpm is close to optimum for the potassium turbine. It should be noted, however, that reducing the cesium turbine speed from 24,000 rpm to 18,000 rpm will lead to an increase in generator weight (see Table 1).

Effects of Turbine Inlet and Outlet Temperatures

Results of the calculations of Tables 5, 6, 10, and 11 have been summarized and plotted in Figs. 15 and 16 to show the effects of the choice of the turbine outlet temperature on the overall cycle efficiency with allowances for aerodynamic, moisture churning, and seal-leakage losses, together with regenerative feed heating. Note that, as one might expect, these points fall on curves that are consistent with the idealized cycle calculations cited earlier in the report. Note, too, that a comparison of Figs. 12 and 16 shows that the effects on the overall cycle efficiency of changing the number of stages would be much less than the effects of either the choice of turbine inlet and outlet temperatures for the sets of conditions considered here or the use of regenerative feed heating.

Some additional insight into the effects on major turbine design parameters of variations in condenser inlet temperature is given by Fig. 17 which was prepared for a series of five-stage cesium and potassium vapor turbines with regenerative feed heating and allowances for aerodynamic, moisture churning, and seal-leakage losses. Other than the increase in cycle efficiency, perhaps the most important effect of reducing the condenser temperature is the increase in diameter of the last stage that results from the rather rapid decrease in vapor density with a drop in temperature. This increase in diameter would be substantially greater were it not for the fact that the number of stages has been kept constant for the points of Fig. 17, and thus the head drop per stage has been increased as the condenser temperature was reduced. Note that keeping the number of stages constant has little effect on the turbine efficiency, however, for the range considered here. It is also evident that the amount of moisture in the vapor entering the last stage increases rapidly as the condenser temperature is reduced, hence moisture removal between the stages becomes progressively more advantageous as the design condenser temperature is reduced for a given turbine inlet temperature. Moisture removal between stages should be particularly helpful in improving the turbine efficiency at the lower condenser temperatures relative to the values given in Fig. 17.

Effects of Regenerative Feed Heating

The effects of regenerative feed heating on the overall thermal efficiency of the cesium and potassium vapor cycles are shown graphically in Fig. 18 as a function of the number of stages in the turbine. Data are presented in Table 15 and Fig. 18 for three basic cycles, the ideal Rankine cycle, a Rankine cycle with a 75% turbine efficiency, and a set of Rankine cycles with a 75% turbine efficiency with regenerative feed heating using a feed heater having a heating effectiveness of 80%. In each instance, bleed-off for regenerative feed heating was assumed between each pair of adjacent turbine stages, that is, a two-stage turbine would have one bleed-off, a three-stage turbine would have two bleed-offs, etc. Note the dramatic improvement in cycle efficiency obtainable through the use of regenerative feed heating. The improvement runs as much as four points in cycle efficiency, or about 18.5%. This would permit a very substantial reduction in radiator size and weight, and appreciable reductions in the size and weight of the reactor and shield assembly. These savings much more than offset the extra weight and complication represented by the introduction of the feed heater.

Bleed-off for regenerative feed heating reduces the amount of work obtained per pound of vapor entering the first stage, and thus makes it necessary to increase the vapor flow to the first stage of the turbine by a small amount. At the same time, it greatly reduces the amount of vapor flowing through the latter stages. The combined effects of these two factors tend to reduce the amount of channel divergence between the first and last stage, an important factor from the standpoint of aerodynamic efficiency. Note, too, that the size and weight of the vapor ducts between the turbine and the condenser will be reduced with the regenerative feed heater. This is especially important if the ducts are fairly long, as they would be if a direct condensing radiator were employed. Note, too, that bleed-off for regenerative feed heating makes it possible to employ to advantage the vapor leaking past the labyrinth seal between the first stage and the adjacent bearing. This leakage represents a relatively small loss with regenerative feed heating, but a substantially larger one if it cannot be used to advantage in this fashion. (In large steam plants about one-third of the steam is bled off for regenerative feed heating, thus greatly easing the design of the last stages of the turbine.)

The disparity in cycle efficiency between the points for the five-stage cesium and potassium vapor turbines was investigated by examining the data in Tables 5, 6, 10, and 11 for the 2150°F/1330°F condition. Note that there is essentially no difference in efficiency between these two turbines yielded by the thermodynamic calculations with no regenerative feed heating, but that the difference amounts to over one percentage point in cycle efficiency (i.e., over 4%) with regenerative feed heating. The points read from the Mollier diagram were rechecked using a magnifying glass, and some small errors in Tables 5 and 6 were found, but these were not nearly large enough to account for this difference. Closer inspection revealed that the amount of heat added to the liquid in the regenerative feed heater represented a substantially larger fraction of the heat of vaporization for cesium than for potassium (note that in both instances the turbines were five-stage units, and the extraction points were at the same temperature). To check this, data were taken from the NRL reports for thermodynamic properties of cesium and potassium (Refs. 17 and 18) and tabulated in Table 16 for cycles designed to operate between a saturated boiler outlet condition of 2150°F and a condenser temperature of 1400°F (these values were chosen to avoid uncertainties associated with interpolation or extrapolation of the NRL tables). Note that in Table 16 the ratio of the heat added to the liquid between the condenser temperature of 1400°F and the boiler temperature of 2150°F represents 28.1% of the heat vaporization for cesium and only 20.9% of the heat vaporization for potassium. Thus the benefi s of regenerative feed heating are substantially greater for cesium than for potassium. It is not clear whether this improvement stems from inherent differences in the physical properties of the two fluids, or whether it is an artifact of the approximations used to correlate the experimental data for the physical properties. This matter is discussed by H. W. Hoffman in a companion report.[19]

Effects of Aerodynamic, Seal Leakage, and Moisture Losses

The data in Tables 5, 6, 10, and 11 were employed to separate and distinguish the various effects of the aerodynamic, seal leakage, and moisture losses. In analyzing these data, some small inaccuracies in the calculations in Tables 5, 6, 10, and 11 were disclosed because the effects of the individual losses were found to be a bit irregular, and these small inaccuracies (mostly associated with difficulties in reading the Mollier diagram for potassium) were corrected. The additional calculations made to separate the various losses are shown in Table 17, and the results are summarized in Table 18.

A good insight into the relative importance of the aerodynamic, moisture, and seal losses is given by Fig. 15 which was prepared for cycles with no regenerative feed heating. The points for the aerodynamic losses were those obtained through the use of Baljé's charts, reproduced here as Figs. 4 and 5. The effects of moisture assuming 1.25% loss in turbine efficiency per percent of moisture is about as great as the sum total of the aerodynamic losses. This points up sharply the possible gains associated with removal of the moisture in a manner that would minimize the amount of liquid churning, that is, transfer of momentum from the rotor to liquid droplets. Porous stator blades appear to offer a promising approach to the removal of the liquid in such a manner.

The effects of flow bypass through the labyrinth seals on the cycle efficiency are also shown in Figs. 15 and 16. Note that the use of regenerative feed heating makes it possible to use much of the leakage past the seal between the first-stage rotor and the adjacent bearing in the feed heater, and this makes the seal loss substantially lower than is the case for the simple nonregenerative cycles.

It is worth noting that both the seal and moisture losses are somewhat greater for potassium than for cesium. The seal losses are definitely higher for potassium because of its higher velocity through the clearance openings in the labyrinth seal. The moisture losses appear to be higher for potassium because an isentropic exapnsion from the dry saturated vapor condition between the same temperature limits gives about 10% more moisture for potassium than cesium according to the NRL Mollier diagrams of Refs. 17 and 18. This difference may be real or it may be simply an artifact of the approximations employed in the construction of the charts. The matter also is discussed in a companion report by H. W. Hoffman.[19]

Effects of Generator and Feed Pump Losses

The effects of losses in the electrical generator and the feed pump are shown in Fig. 16. The generator losses were the same for cesium and potassium. The feed pump losses were higher for cesium than for potassium, but the effect is so small that it is not apparent in Fig. 16. However, it does have a large effect on the size and weight of the feed pump and its auxiliaries if an electromagnetic pump is employed.[20]

REFERENCE DESIGNS

Consultation with S. V. Manson, W. L. Stewart, A. J. Glassman, J. A. Heller, and J. P. Joyce of NASA led to the selection of a series of reference designs for detailed analysis. The curves shown in Figs. 12 and 13 span the range of interest. For one set of reference designs it seemed well to choose the number of turbine stages to give a turbine efficiency close to the peak obtainable, and this led to the choice of a three-stage cesium turbine and an eight-stage potassium turbine. In addition, it seemed well to consider a pair of turbines having the number of stages reduced to the point where the loss in turbine efficiency would run approximately one percentage point, and this led to the choice of a two-stage cesium turbine and a five-stage potassium turbine.

In selecting rotor and bearing configurations, two basic cases were considered: a) the turbine and generator rotors each straddle-mounted and connected by a quill shaft to give a four-bearing machine, and b) the turbine stages overhung from the end of the generator rotor to give a two-bearing machine. It was decided that it would be well to look at both two-bearing and four-bearing machines for the three-stage cesium turbine and the five-stage potassium turbine. In addition, a two-stage cesium turbine in a two-bearing machine and an eight-stage potassium turbine in a four-bearing machine appeared appropriate. Table 19 summarizes these six cases.

The moisture removal and erosion problems are rendered less severe for those cases in which the number of stages is small or the rotor is split as was contemplated in the five-stage potassium turbine in a two-bearing machine (with the first three stages of the potassium turbine at one end of the generator and the other two stages at the other end). As a consequence, only four of the above six cases were considered for detailed analysis of the moisture removal problem.

Layout Studies

Layouts were prepared for each of the six cases in Table 19. Two drawings were prepared for each case; one drawing was intended to show the principal details of the turbine construction while the other was prepared to specify the key dimensions involved in the studies of the rotor and bearing dynamics. These drawings are presented in Figs. 19 through 30.

It is believed that the drawings showing the details of construction of the turbines make it possible to satisfy all of the boundary conditions summarized in Table 2. In the time available it was not possible to prepare the additional drawings required to show many minor details that were considered and for which allowances were made by allocating the space required, etc., but it is believed that these details would have little effect on the evaluation of the relative merits of cesium and potassium as working fluids.

Inasmuch as the layouts of Figs. 19 to 30 had to be prepared before making the final set of iterative calculations summarized in Tables 21 and 22 there are some disparities in blade height and stage diameter between these dimensions in the layouts and the corresponding values in Tables 21 and 22. These disparities are small, and simply mean that the blade height and stage diameter should be obtained from the tables rather than by scaling from the drawings.

Aerodynamic Considerations

The first step in preparing the layouts in Figs. 19 through 30 was to repeat the calculations of Tables 5, 6, 10, and 11 using — where available — the overall turbine efficiency implied by those tables rather than the value of 75% assumed in Tables 5 and 6. The results are tabulated in Tables 20 and 21. In making the thermodynamic calculations of Table 20, the amount of reheat to be expected from the adiabatic expansion was found by taking the product of the aerodynamic efficiency and the efficiency associated with the moisture churning losses.

In employing the data of Tables 20 and 21 in preparing the layouts, some changes in rotor diameter and blade height were made to assure that the inlet nozzle angle would not be less than 15 deg, that the flow from the rotor into the subsequent stator would be within 15 deg of axial (to avoid divergence in the channel through the stator inlet vanes), and the diameter was stepped fairly uniformly from one stage to the next. An examination of Baljé's charts indicates that the procedure followed in the preparation of Table 21 is such that variations in diameter up to around 10% can be made in the vicinity of the diameter for maximum efficiency with little effect on the efficiency. With these modifications to the turbine proportions, the layouts of Figs. 19 through 30 were prepared together with the dimensional and performance data of Table 22. Note that splitting the five-stage potassium turbine so that three stages might be mounted at one end of the generator and two stages at the other to give a two-bearing machine cause increased aerodynamic losses between the third and fourth stages (for which no allowance was made in the data presented in Table 22).

The velocity diagrams for the various cases are presented in Figs. 31 through 34. Note that, in preparing these, the axial velocity was selected to yield a minimum stator exit angle of 15 deg, which in turn meant adjusting the blade height in accordance with the rotor diameter chosen from aerodynamic passage layout considerations.

It was difficult to decide how best to handle the increases in diameter from one stage to the next as implied by the calculations of Tables 10, 11, and 21. Rotor stress considerations (to be discussed in the next section) strongly favor keeping the first stage rotor diameter to a minimum. This stems from the fact that the small balde height in the first stage rotor makes the performance of that stage quite sensitive to the tip clearance. The first stage tip clearance, with allowances for distortion and creep over a 20,000- to 40,000-hr rotor life, would be likely to run on the order of 10% of the blade height, which would give a loss in efficiency in the first stage as a consequence of tip leakage of perhaps 15%. Note that, for a given set of conditions, this loss will increase rather rapidly with an increase in stage diameter — as will creep in the rotor. In view of the rather large losses associated with flow bypass through the labyrinth seals at the hub and the need for pronounced thickening in the web of the rotor at the hub, it was found difficult to keep the centerline spacing between rotors to less than 1.25 in. As can be seen in Fig. 19, for example, this relatively wide spacing makes it possible to obtain a passage layout having a longitudinal section in which the radius of curvature of the S-shaped passage connecting the two rotor stages is large relative to the radial thickness of the passage, and hence the S-shaped passage should not give serious difficulty with flow separation, and the aerodynamic losses associated with distortion of the velocity distribution should not be too serious. Note, too, that the stator exit angle is only 15 deg, and that the stator pressure ratio in most cases is close to two or greater, so that the stator blading is quite different from that for a conventional reaction turbine. Another approach would be to employ essentially conical passage walls for the rotor casing, but this greatly complicates both the design and the fabrication of the rotor blades without yielding a clear-cut performance advantage. As a consequence, the flow through the rotors was kept axial and the stage diameters were stepped as shown in Figs. 19 through 30 as a compromise measure because no clearly better approach was evident.

Generalized diagrams for the rotor and stator blading in Figs. 19 through 30 are presented in Figs. 35 and 36, while Tables 22, 23, and 24 summarize the principal dimensions for the four cases to be examined in the moisture removal analyses. Note that the axial width of the turbine blades has been tapered in the radial direction so that the blade profile generated by a conventional end-milling procedure will yield the appropriate blade angle variation from root to tip. Similarly, the stator blade layouts were made to be elements of an elliptical cylinder with the leading edge defined by a slice through the cylinder at an angle chosen to give the proper variation in the inlet angle as required by radial variations in the direction of the rotor exit velocity vector from the previous stage.

The relatively large changes in diameter from one stage to another led to rather complex stator flow passages. For the moisture removal analysis it was necessary that analytical expressions be defined for these passages. In doing this, several approaches were tried, and it was found that a simple way of handling the problem was to specify that the longitudinal projection of the pitch line would be in the form of a sine curve, with the stator blade length representing one-half cycle, as shown in Fig. 37. The dimensions given on the curves are in inches, and the symbols used are defined in the table of nomenclature given in this section. The inner and outer walls of the passage would be generated by a circle whose diameter would vary according to an appropriate schedule as discussed below. Figure 38 shows a diagram similar to that of Fig. 37 except that it is for the circumferential projection of the stator blades.

Nomenclature

A_s	Stator flow passage area normal to the local mean flow direction
d	Diameter of a circle tangent to both boundaries of passage in the circumferential projection
$\bar{D}$	Passage mean line diameter
D_p	Diameter of radial projection cylinder
h	Blade height
S	Wheel centerline spacing
L	Stator axial length
w	Blade width of turbine bucket in axial direction
y	Circumferential distance on radial projection cylinder
z	Distance in the axial direction (parallel to turbine centerline)
θ	Angle between flow direction and turbine centerline
φ	Nozzle exit angle

Subscripts

0	Inlet, $z = 0$
L	Exit, $z = L$
t	Throat

Added

D_0, D_L	Stator inlet and exit OD, respectively
A_t	A_s at $z = z_t$
a	Ellipse semi-minor axis

Stator Flow Passage Area

The stator passage flow area is defined as a function of axial distance, z, along the turbine centerline by

$$A_s = \pi \, d \, \overline{D} \cos \theta \, . \tag{1}$$

The various terms appearing in the equations presented here will be found defined in the Nomenclature in the previous section.

The direction of the flow in the developed radial projection is defined by

$$\cos \theta = \frac{1}{\sqrt{1 + \tan^2 \theta}} \, , \tag{2}$$

where $\tan \theta$ is the slope of the stator blade contour in the radial projection, that is,

$$\tan \theta = \frac{dy}{dz} = y' \, . \tag{3}$$

In the radial projection, the stator blade contour is a quarter-ellipse defined by

$$Az^2 + By^2 + Czy + Dz + Ey = 0 \, , \tag{4}$$

with

$$A = 1 + 3 \cos^2 \varphi \, ,$$
$$B = 1 + 3 \sin^2 \varphi \, ,$$
$$C = -3 \sin 2\varphi \, ,$$
$$D = -4 \, a \sin \varphi \, ,$$
$$E = -4 \, a \cos \varphi \, .$$

The semi-minor axis, a, of the ellipse is given by

$$a = \frac{L}{\cos \varphi + 2 \sin \varphi} \, . \tag{5}$$

The axial length, L, of the stator blade is found from

$$L = S - \frac{1}{2}(w_0 + w_L) - 0.35 \, . \tag{6}$$

The constant, 0.35, arises from an allowance of 0.10 in. at the stator inlet and 0.25 at the exit, the latter for droplet acceleration. Finally, the slope, y', is determined from

$$y' = -\frac{2Az + Cy + D}{Cz + aBy + E} . \tag{7}$$

In order to minimize angular deviations resulting from the change in stator radius from inlet to exit, the projection cylinder diameter (i.e., the constant radius circular cylinder on which the radial view of the stator is projected) is taken to be the mean of the inlet and exit mean diameters. Thus,

$$D_p = \frac{1}{2}[(D_0 - h_0) + (D_L - h_L)] . \tag{8}$$

The diameter of the passage mean line in the circumferential projection is given by

$$\bar{D} = (D_0 - h_0) + [(D_L - h_L) - (D_0 - h_0)] \sin^2 \frac{\pi s}{2L} . \tag{9}$$

Specification of the flow area can now be completed by defining d, the diameter of the circle tangent to the passage boundaries in the circumferential projection, as a function of z. The supersonic case will be considered first.

With the throat area, A_t, and location, z_t, specified, we find d_t from Eq. (1), rewritten as

$$d_t = A_t/\pi \bar{D} \cos \theta , \tag{10}$$

where all quantities on the right hand side are evaluated at $z = z_t$. The stator throat is located by specifying that the arc length from exit to throat be equal to the separation distance between the same exit and throat areas in an equivalent circular cone of specified divergence angle. Because of the favorable pressure gradient, one can use a rather large angle, say 20 deg.

We now take a linear variation of d from inlet to throat and from throat to exit, that is,

$$d = \frac{d_t z + h_0(z_t - z)}{z_t}, \qquad 0 \le z \le z_t , \qquad (11)$$

and

$$d = \frac{d_t(L - z) + h_L(z - z_t)}{L - z_t}, \qquad z_t < z \le L . \qquad (12)$$

The subsonic case is handled by ignoring Eq. (10) through (12) and simply specifying a single linear variation of d from inlet to exit, that is, we have

$$d = \frac{h_L z + h_0(L - z)}{L} \qquad 0 \le z \le L . \qquad (13)$$

Stress and Creep in the Rotor

Creep-stress limitations present a major problem in the design of the rotors for the first one or two stages. Some indication of the severity of the problem is given by Fig. 39 which shows two curves, one for the stress in a typical turbine rotor as a function of tip speed, and the other for the stress that would give a creep rate of 0.5% per 10,000 hr. These curves show the importance of reducing both the rotor tip speed and the rotor temperature. This problem is vital, and will be treated later in detail.

One advantage of the impulse turbine is that the temperature drop in the nozzle ahead of the turbine leads to a lower static temperature for the vapor passing through the turbine wheel than the static temperature prevailing at the inlet to the stator for that stage. However, as the pressure ratio and temperature ratio across the stator are increased, it is necessary to increase the turbine wheel tip speed in order to make effective use of the higher velocity jet associated with the higher temperature and pressure ratio across the stage. The higher tip speed leads to increased stresses, and this may more than offset the increased allowable stress in the turbine wheel as a result of its lower operating temperature. In an effort to determine the net effect, data were taken from Tables 10 and 11 for the first stage of 4-, 5-, 7-, and 9-stage potassium turbines, and 1-, 2-, 3-, and 5-stage cesium turbines. The first stage tip speed and temperature drop were entered in Table 25, and the stress corresponding to that tip speed was taken from Fig. 39. The static temperature corresponding to that stress was also taken from Fig. 39 to give the maximum allowable static temperature of the vapor passing through the turbine wheel, and hence the turbine wheel temperature. To this value was added the temperature drop in the stator to yield the vapor temperature entering the stage. The latter data were then plotted in Fig. 40. These data indicate that a nine-stage potassium vapor turbine could be operated with a turbine inlet temperature about 50°F above that for a five-stage potassium vapor turbine. Similarly, a three-stage cesium turbine could be operated at a temperature about 80°F above that for a two-stage turbine, while a single-stage cesium turbine could be run at a temperature about 150°F above that for a two-stage unit. However, the single-stage cesium vapor turbine would be likely to give other difficulties, as indicated in earlier discussions. Thus, it appears from Fig. 40 that, from the standpoint of creep in the turbine wheel, there is little gain in a turbine inlet temperature obtainable through an increase in the first stage pressure ratio.

An important point shown by Fig. 40 is that, if creep stresses in the first stage turbine wheel were the controlling consideration in the selection of the system operating temperature, cesium would permit an increase in the turbine inlet temperature of about 300°F relative to the corresponding value for potassium. However, it appears that creep stresses in the fuel elements, which will have to run hotter by 300°F or more, will be more likely to limit the vapor temperature entering the turbine than turbine wheel stresses, hence the advantage of cesium will be that it will provide a greater margin between the design stress and the creep limit or provide more latitude in the design of the turbine.

Rotor Balancing

The stacked disc casing and rotor configuration employed here has the disadvantage that final balancing of the rotor would have to be carried out with the rotor and casing assembled. At the outlet end, the rim of the last stage of the rotor would be readily accessible for removing material. At the inlet end it would be necessary to remove material at a relatively small radius, that is, at the outer perimeter of the hub just in-board of the bearing.

Rotor Masses and Moments of Inertia

To provide data for the rotor and bearing dynamics analyses, each rotor in the layouts of Figs. 19 through 30 was broken down into a large number of small, simple, geometric elements for which the weight and polar moment of inertia could be estimated. The values for the various small elements were then summed to provide weights and moments of inertia for each wheel in the turbine and each stub-shaft at either end of each turbine rotor. Similarly, the Westinghouse data summarized in Table 1 for the generator was employed to estimate the weight and moment of inertia of the generator rotors. In addition, a coupling weight was estimated for the four-bearing machines. Results of these calculations are summarized in Table 26.

Turbine Casing Design for Dimensional Control

A major problem in the layout of the casing for a high temperature turbine is the development of a detail design that will lend itself to fabrication and assembly, give good centering of the various parts to provide good bearing alignment and permit small running clearances, accommodate the necessary amounts of differential thermal expansion, minimize bypass leakage, and avoid heat losses associated with vapor condensation on surfaces at temperatures below that corresponding to the local saturation pressure. In the layouts of Figs. 19 through 30 considerable care has been taken to reduce the temperature gradients and thermal stresses by making the interstage diaphragms conical and by adding membranes for thermal insulation. Care has been taken in designing these diaphragms and membranes so that they will accommodate whatever pressure differential might occur across them.

An important question associated with the layouts of Figs. 19 through 30 is the degree to which tolerances may tend to build up in the stack of casing or rotor elements and lead to sufficient eccentricity to cause a rub in the interstage labyrinth seals or at the rotor blade tips. In an effort to analyze this, Fig. 41 was prepared to show the basic geometric relations. The width of the conical surface forming the joint between adjacent sections of the casing is referred to as w, while the distance from the inner edge of the conical mating surface to the shaft center line measured along an element of a cone perpendicular to the mating surface was taken as R, and c_1 was taken as the distance from the apex of the aforementioned cone to the outer edge of the conical mating surface. The principal form of misalignment that might result from this structural geometry appears to be analogous to that to be expected from slipping one sphere inside another (where the conical surfaces are taken as approximations to a sphere). Such a slippage would cause the distance w_1 to be reduced to w_2 and, at the same time, the length c_1 would be reduced to the length c_2 of Fig. 41. The difference between c_1 and c_2 as compared to the difference between w_1 and w_2 then gives an indication of the amount of misalignment that might accrue from a given deviation from ideality in the fabrication of the surfaces. The relation between these two differences can be derived quite simply on the basis of relations that can be deduced from Fig. 41.

The results of the above derivation coupled with an inspection of the turbine layouts of Figs. 19 through 30 indicates that, if the concentricity error associated with a 45 deg conical joint between two casing sections is to be kept to 0.001 in., the conical surfaces should have the same slope within 0.001 in. This will require either that the parts be lapped together in a special fixture before final assembly or that the final surface finishing operation be carried out in the same machine with the same compound cross-slide setting to generate the conical surfaces of the mating parts. Note, too, that the precision required for a given permissible build-up in eccentricity is a function of the number of stages because of tolerance accumulations.

To avoid difficulty with buckling or other damage to the thin membranes, the space between the membrane and the diaphragm would be vented to a lower stage pressure or the turbine discharge pressure, and spiral wires or embossed stand-off points would be provided on sufficiently close centers to support the membrane in such a way that the bending stresses induced in the membrane would be acceptable.

Size and Weight of Reference Design Units

The overall diameters and lengths of the six reference design turbine-generator units were scaled from Figs. 20, 22, 24, 26, 28, and 30 and summarized in Table 27. The weights of the rotors were taken from Table 26, and the weights of the casings including the outer shell (for hermetic sealing) were estimated and tabulated. Inasmuch as the weight of a turbine stage increases as the cube of the diameter, the larger diameter of the potassium turbines increased the turbine weight by roughly a factor of two over the corresponding cesium turbines. In addition, for a given turbine efficiency the greater number of stages for the potassium turbine evidently lead to an additional factor of two increase in weight for the potassium turbines.

In making the weight estimates there was no attempt to allow for weight reductions that might be effected by refining the details of the design. It is difficult to estimate to what extent wall thicknesses might be reduced by using ribs, milling out recesses, or the like short of a quite detailed analysis, but it appears that substantial savings would be possible. On the other hand, it is possible that some important items that would increase the weight substantially have been overlooked. In the balance it is believed that the values given in Table 27 represent overestimates of the weights, and the effect of this is probably to penalize the potassium turbines somewhat in comparing the potassium and cesium system weights.

ANALYSES OF SPECIAL PROBLEMS

Very early in the design study it became evident that four major problem areas were so deserving of special attention that each should be attacked by a group of specialists and their work covered in a separate report. The first of these — turbine bucket erosion — was so vital to the layout of the reference design turbines that an extensive survey of the literature was carried out concurrently with the parametric studies, and the results were summarized in a report.[9] The other three major problem areas were creep in the first stage rotors, bearing and rotor dynamics and temperature distribution and thermal stresses. All of these have been discussed in general terms in previous sections, but detailed analyses could not be undertaken until detailed reference designs were available. In view of the great technical difficulty of the problems, the high order of technical competence required to cope with them, and the need for special computer programs, it was deemed best to seek assistance outside of ORNL. A subcontract was arranged with Mechnical Technology, Inc. to estimate the amount of creep to be expected in the first stage rotors of the reference design turbines, to design bearings suitable for each of the reference design turbines, and to investigate the bearing and rotor dynamics for each of the reference design turbines. Similarly, a contract was arranged with the Westinghouse Astronuclear Laboratory to make a detailed analysis of moisture formation, deposition, and possible turbine bucket erosion in the reference design turbines. Extensive experience with thermal stress problems at ORNL led to the conclusion that it would be just as well to handle these problems in the reference design turbines within the ORNL organization.

Detailed presentations of these specialized design studies and analyses are presented in companion reports.[21-23] A brief summary of the results is presented in the following sections together with a discussion of the modifications in the reference design that are shown to be in order by these studies.

Rotor Creep Stress Analysis

The rough preliminary rotor creep analysis presented earlier clearly showed the need for a more refined analysis, and this was arranged. ORNL supplied MTI with the data on the reference designs presented in the previous section together with what data could be found by ORNL metallurgists on creep and creep rupture in TZM, the molybdenum alloy chosen for the rotor. MTI correlated the latter data using a Larson-Miller plot to develop charts for the creep analysis work. These data were then applied to estimating the creep in the reference design rotors using a modification of a technique developed at the NASA-Lewis Laboratory for turbo-jet engines.[24] The results of the study are presented in Table 28 in which the upper portion represents the data developed at ORNL for the reference designs, the central portion gives the data on bearings and bearing and rotor dynamics developed at MTI, and the last portion summarizes the MTI rotor creep stress analyses. These results show that the cesium reference designs would yield a radial growth in the first stage less than 0.003 in. in 40,000 hr, and hence are acceptable from the creep standpoint. The potassium turbines, however, were found to have excessive creep stresses and growth so that some modification would be essential. One approach would be to reduce the turbine inlet temperature. Figure 42 shows the effects of turbine wheel operating temperature on the growth of the wheel for 40,000 hr of operation. These curves indicate that the turbine inlet temperature would have to be reduced by over 100°F to bring the growth rate within acceptable limits.

To avoid the loss of performance that a reduction in the turbine inlet temperature would entail it seemed in order to consider the possibility of reducing the stresses by reducing the diameter of the first stage rotor. Figure 5 shows that reducing the rotor diameter at a constant specific speed results in only a small loss in efficiency in the region in which the first stage potassium rotors fall, that is, at the extreme left end of the constant efficiency "contour lines" in Fig. 5. An examination of the curves in Fig. 39 indicates the reducing the diameter by about 22% would reduce the stress by about 40%, and this would have about the same effect on creep as reducing the turbine rotor temperature by 125°F. An examination of Figs. 15 and 16 indicates that reducing the turbine inlet temperature would result in a loss of about one point in overall cycle efficiency, whereas Fig. 5 indicates that reducing the diameter of the first stage 22% would cause a loss of about 3 points in the efficiency of the first stage. This would amount to about half a point loss in the overall efficiency for the turbine, and only about two-tenths of a point in the overall cycle efficiency. Thus it appears that the better course would be to reduce the diameter of the first stage rotor in each of the potassium reference design turbines.

Bearing Rotor and Dynamics

Discussions with both MTI and the Aerospace Electrical Division of Westinghouse in the course of the preliminary design work disclosed that MTI was carrying out a set of bearing and seal design studies for a Westinghouse generator similar to that chosen for this study. As a consequence, a subcontract was arranged under which it was agreed that ORNL would supply MTI with turbine and generator layout drawings in which the bearing regions were left vague with the intent that MTI would specify the detailed proportions of these regions. Thus the first step in the MTI study was to develop a set of bearing layouts for the two-bearing and four-bearing machines, and these are shown in Figs. 43 and 44. The MTI studies showed that four tilting pads in each bearing gave the most promising arrangement, and this configuration was used in all cases because it avoids difficulties induced by shaft whip in turbulent film hydrodynamically lubricated bearings, and this greatly eases the problems of obtaining an acceptable bearing and rotor configuration for the reference design turbines. Further, it is inherently self-aligning, hence insensitive to distortion.

It may be noted that the basic layout for the four-bearing machines includes a thin-walled section in the shaft between the first stage rotor and the adjacent bearing, and that for the two-bearing machines has a thin-walled section between the last stage rotor and the adjacent bearing. This was done to provide a heat dam both to reduce the heat loss to the bearings and to reduce the thermal stresses in the hub region where the thermal gradient would be high. As will be discussed in the next section, the temperature distribution and thermal stress studies carried out at ORNL indicate that the heat dam regions would not be necessary if the rotor were segmented as in Figs. 19 to 30.

Frictional Horsepower

The power losses associated with fluid friction in the bearings not only reduce the net power output of the turbine-generator but also increase the heat load on the radiator. These losses were calculated by MTI and are summarized in Table 28 in the third from the last line of the table. The 2.0 in. diameter journals for the four-bearing machines gave about one-quarter of the frictional loss per bearing given by the 3.0 in. diameter bearings used in the two-bearing machines. As a consequence, the overall bearing frictional power losses in the turbine-generator units ran about half as much for the four-bearing machines as for the two-bearing machines.

Critical Speed Analyses

In attempting to summarize the results of the MTI analyses it was noted that the critical speeds for the alternators were close to those for the turbines. As a consequence, each critical speed value given in Table 28 for a four-bearing machine is a mean between that for the turbine and that for the generator.

It should be pointed out that the first two critical speeds in all the cases analyzed were rigid body criticals and the third critical speed is a flexural one. Analysis by MTI of the unbalance response of each of the damped rotor bearing systems showed that the amplitudes of the rotor when passing through the first two critical speeds were not excessive.

Turbine-Bucket Erosion Analysis

ORNL supplied the data on the four reference designs (presented in previous sections) to the Westinghouse Astronuclear Division for use in their computing machine programs for estimating the moisture formation in the course of the expansion of wet vapor in passing through a turbine, the extent to which the moisture will tend to deposit on rotor and stator blades, the behavior of the liquid dribbling off the stator blades, and the threshold for damage to the rotor blades.

The Westinghouse study (reported in Ref. 22) began by estimating the amount of moisture present in the vapor as a function of axial position in the turbine. In all cases the droplet diameters were found to be less than 1 micron for both cesium and potassium. The amount of moisture that deposited in the various blade rows was then calculated and in no instance was it as much as 4% of the total moisture present in the vapor at that station. The initial diameter of the liquid droplets shed from the trailing edges of the stator was then calculated together with the extent to which these droplets would be accelerated and broken up into smaller droplets. From these calculations the velocity of the droplets relative to the rotor at the point at which they would strike the turbine buckets was calculated and in all instances was found to be less than 800 ft/sec. The droplet diameter at the point of interception was found to range from 1 to 5 microns for cesium, and from 8 to 26 microns for potassium for the last stages of the reference designs.

Following Pouchot's thesis that the threshold velocity for damage varies with the droplet diameter and the Vickers diamond point hardness of the blade material, the last portion of the analysis was concerned with the estimation of the threshold velocity for damage for each of the four reference designs considered using the range of diameter for the drops impacting on the last stage rotor as the basis for the estimates. The results are summarized in Table 29. Note that in all instances the threshold velocity for damage to TZM blades is at least three times the actual relative velocity between the droplet and the blade, and hence droplets dribbling off the stator and impinging on the rotor should not cause turbine bucket erosion in the reference designs.

In view of the large margin available between estimated operating conditions and the point at which turbine bucket erosion would become a problem, consideration was given in the Westinghouse report[22] to the possibility that the provisions for moisture removal between stages shown in the reference designs might be eliminated. It was concluded that the interstage moisture removal provisions are necessary because otherwise the liquid film traveling along the wall of the outer casing would build up to the point where large droplets would be torn from wave crests and would impinge on turbine buckets where they would cause damage. Further, lash of such droplets back and forth between the rotor and the casing could cause substantial amounts of damage to the casing.

Four different values of VPN were used to bracket potential bucket materials. These were:

VPN	Typical Material
190	12% chrome steel
260	TZM
400	Stellite 6
500	Maraging steel

Thermal Stress Analyses

A substantial effort was made to determine the temperature distribution in the rotor and stator of the reference design turbines and from these temperature distributions to determine the thermal stresses. Segmentation of the rotor and stator to provide heat dams between stages, while an effective technique from the standpoint of reducing thermal stresses, greatly complicates the computational process. It was found necessary to develop a new computer program to allow for the discontinuities represented by the parting surfaces between stages. Such a program was developed to define the temperature distribution in the rotor, and a second program was adapted from an existing one to determine the thermal stresses in any given segment using the temperature distribution as input. The results of these analyses indicate that segmentation reduces the heat losses associated with axial heat flow, and appears to keep thermal stresses within acceptable limits in all of the reference designs. The details of these calculations are presented in Ref. 23.

An attempt was made to carry out a similar series of analyses for the casings. However, the complexities of the geometry are such that a workable program was not developed within the limits of the time and funds available.

The most severe thermal stresses in the rotors were found in the four-bearing machines and occurred in the hub between the bearing at the high-temperature end and the first stage rotor. These require careful attention in the design, but either the segmented rotor shown in the reference designs of Figs. 19 through 30 or the thin-walled shaft arrangement proposed by MTI[21] (see Fig. 44) appear entirely adequate to keep the thermal stresses well within acceptable limits. Another area that threatens to yield thermal stress difficulties lies in the casing between the turbine and the generator. The most severe thermal stresses in this region occur in the two-bearing machines as a consequence of the short distances over which the difference in temperature must be distributed. Crude order of magnitude calculations indicate that these problems can be handled, but time did not permit a definitive study.

An attempt was made to analyze the local thermal stresses in the turbine buckets associated with the stagnation temperature rise in the vapor at the leading edge of the blade. For example, if the blade leading edge were approximated as a cylinder with a radius of 0.010 in., the temperature spike would occur over a distance of about 0.005 in. The effect of this highly localized impact temperature rise in the vapor on the temperature distribution and hence the thermal stress in the rotor blade is difficult indeed to resolve. However, there is reason to believe that the liquid film on the blades that is so important in minimizing erosion by droplet impact will also serve to diminish the effect of the impact temperature spike as a consequence partly of heat transport by the flowing liquid film and partly by re-evaporation of the liquid. In short, the analysis indicated that the relationships are very complex and probably can be resolved only by a well-thought-out series of experiments. In any event, there appears to be very little difference between cesium and potassium if the same number of turbine stages is employed, but the effect becomes progressively more pronounced as the number of stages is reduced and the temperature drop per stage is increased.

NOMENCLATURE

A	Area, ft^2
a^*	Cutter diameter, ft
C	Chord length, ft
C_o	Spouting velocity
c_p	Specific heat at constant pressure, Btu/lb·°F
D	Rotor diameter, ft
D_s	Specific diameter, ft
g	Gravitational constant, ft/sec^2
H	Head, ft
h	Blade height, ft, and enthalpy, Btu/lb
J	Rotor blade chord, in.
M	Mach number
N	Rotative speed, rpm
N_s	Specific speed
n	Number of stages or nth stage
P	Pressure, psia
r	Radius, in.
Re	Reynolds number
S	Entropy, Btu/lb·°F
s	Tip clearance, ft
T	Temperature, °R
t	Blade pitch, ft
U	Peripheral speed, fps
V	Volume flow, ft^3/sec
v	Specific volume, ft^3/lb
W	Weight flow, lb/sec
w	Relative velocity, ft/sec
X	Vapor quality
α	Absolute angle, deg
β	Relative angle, deg
η	Efficiency
μ	Dynamic viscosity, lb/ft·sec

Subscripts

ad	Adiabatic
c	Cycle, condenser
is	Isentropic
ℓ	liquid
m	Mean
s	Specific, sound
sv	Saturated vapor
t	Turbine
1	Inlet of stage
2	Before turbine rotor
3	Outlet of stage

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Table 1. Effects of Design Speed and Frequency on the Size and Performance of a Series of Inductor Alternators for Space Power Plants[6]*

Coolant temp., °F	800	800	800	800	800
Rating, kva	400	400	400	400	400
Power factor, lagging	0.85	0.85	0.85	0.85	0.85
Frequency, cps	2000	2000	2000	1200	1200
Voltage, L-N	500	500	500	500	500
Speed, rpm	15,000	20,000	24,000	24,000	18,000
Number of poles	16	12	10	6	8
Pole width, in.	1.64	2.01	2.30	3.95	3.21
Stack length, in.	3.54	3.29	2.92	3.39	3.78
Length between stacks, in.	2.49	2.44	2.60	2.37	2.22
Rotor OD, in.	12.51	11.51	11.03	11.55	12.38
Rotor core OD, in.	7.94	7.15	6.63	7.14	7.80
Rotor ID, in.	0.53	0.46	0.42	0.37	0.37
Polar mom. inertia, in.·lb·ft^2	6.897	4.519	3.340	4.632	6.840
Rotor weight, lb	192	150	124	155	195
Pole face losses, watts	3536	1476	2583	640	2402
Pole tip temperature, °F	950	950	950	950	950
Material of rotor	H-11	H-11	H-11	H-11	H-11
Frame OD, in.	21.69	20.05	18.93	19.61	20.75
Frame ID, in.	19.56	18.13	17.21	18.263	19.23
Stator OD, in.	15.78	15.03	14.64	16.40	16.26
Stator ID, in.	12.71	11.72	11.23	11.75	12.58
Total elec. weight, lb	528	430	363	440	500
Stator losses, watts	20,800	22,200	21,500	18,835	17,703
Windage losses, watts	172	235	229	366	258
Vapor density in rotor cavity, lb/ft^3	0.00033	0.00028	0.00025	0.00025	0.0003
Hot spot temp., °F	<1058	<1148	<1220	<1328	<1184
Vapor viscosity, lb/hr·ft	0.0396	0.0396	0.0396	0.0396	0.0396

$$\text{Windage Loss} \sim \rho^{.86}\,\mu^{.14}$$

*Data Supplied by Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio.

Table 2. Summary of Design Precepts for Potassium and Cesium for 300 Kwe Nuclear Space Power Plants

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1. Turbine Speed

(a) The turbine should be directly coupled to a 1200 cps generator, hence its speed will be 14,400, 18,000, or 24,000 rpm.

(b) The relative velocity of the vapor entering the turbine should not exceed a Mach number of unity to avoid compressibility losses.

2. Bearings and Rotor Dynamics

(a) Condensed vapor feed through a Micropore filter will serve as the bearing lubricant.

(b) Tilting pad (or similar) bearings should be used with radial loads kept to less than 50 psi.

(c) The rotor length and weight should be kept low, that is, the turbine diameter and tip speed should be chosen to give a minimum number of stages consistent with good efficiency.

(d) Loads on thrust bearings should be less than 5 psi. This requires the use of nearly pure impulse blading, split flow, or folded flow through the rotor.

(e) Bearing instability and shaft whip must be avoided.

(f) It is desirable to keep the first critical speed of the rotor above the operating range. Under any circumstances the third critical speed of the rotor should be well above the operating range, and, for such designs, damping in the bearings must be sufficient to permit transient operation through the first and second critical speeds if these are below the design speed.

(g) The design should be such that the estimated temperature distribution will not lead to thermal distortion in the rotor or casing that would change the bearing film thickness more than 10^{-5} in. from one end of the bearing to the other as a consequence of misalignment, ovality, etc.

(h) Axial leakage of lubricant from the bearings into the rotor blade region should be kept small to avoid moisture churning losses.

(i) The bearing surfaces should be of tungsten carbide or other material compatible with the working fluid.

3. Seals

(a) In small turbines the amount of flow bypassing the stator nozzles through a casing split on the horizontal center line is likely to represent a large loss, hence the casing should be assembled by stacking rotor and stator discs alternately. The

Table 2. (continued)

rotor discs can be joined by a central, hollow, through bolt, and the stator casings by a set of bolts around the outer perimeter.

(b) The stator blades should be coupled to diaphragms with labyrinth seals fitted to the rotor hub to reduce leakage.

(c) The labyrinth seals should be designed to keep bypass flow losses to 1% if practicable.[13,14]

(d) Labyrinth seals should have sufficient shaft clearances so that contact with the shaft can never occur. (High leakage is preferable to shaft whip induced by possible contact.) A minimum clearance of 0.001 in. per inch of rotor diameter appears reasonable (see Ref. 14).

4. Regenerative Feed Heating and Moisture Removal

(a) Regenerative feed heating should be employed to improve the cycle efficiency and thus reduce the size, weight, and cost of the reactor and radiator. It also contributes to flow stability in the boiler and reduces thermal stresses in the boiler.

(b) Interstage bleeds should be provided to remove moisture between stages to inhibit turbine bucket erosion and reduce churning losses.

(c) Leakage outboard from the first stage wheel through the labyrinth seal toward the adjacent bearing should be adjusted to give up to 75% of the desired flow to the appropriate stage of the feed heater.

(d) Vapor will be bled from the exit of each rotor except the last and from each stator except the first to give up to four bleed stages. For turbines with more than five stages, bleeds should be placed between alternate pairs of stages. The bleed flow from each stator casing will be combined with that from the corresponding point in the labyrinth seal on the shaft and fed to the appropriate stage in the feed heater.

(e) Heat dams should be used to prevent appreciable condensation on parts such as nozzle diaphragms that are exposed to two vapor regions at substantially different pressures and temperatures.

5. Generator

(a) The generator should be a liquid-cooled 1200 cps machine with liquid metal-lubricated bearings.

(b) The generator should be designed so that it can be seal-welded into the same outer housing as the turbine to avoid the need for a zero-leakage shaft seal.

Table 2. (continued)

6. Thermal Stresses and Distortion

   (a) Thermal sleeves should be provided to minimize thermal stresses around penetrations.

   (b) Conical webs should be used where possible to minimize the effects of radial temperature differences.

   (c) Conical mating surfaces should be used where good alignment (and/or a seal) is required between coaxial stationary parts having different coefficients of expansion or operating at different temperatures.

   (d) Temperature differences within any given part should be less than 100°F unless the temperature distribution is such that 100 thermal strain cycles will not be likely to cause a failure.

   (e) The high-temperature vapor should enter the casing through two or more symmetrically placed penetrations.

   (f) Where practicable, the materials of construction should have a low coefficient of expansion.

7. Maintainability and Fabricability

   (a) The complete turbine rotor, stator, and bearing assembly should be removable from the power plant by cutting only a single seal weld and removing a few nuts or cap screws. No lines should enter the cover plate to interfere with its removal.

   (b) It should be possible to test the complete rotor, stator, and bearing assembly outside the turbine casing to check for balance, bearing leakage, and aerodynamic performance.

   (c) The materials of construction should be such that no galling or self-welding will occur between mating surfaces in bolted assemblies.

   (d) The rotor and stator should be fabricable by Eloxing to cut the cost of experimental units.

   (e) Small blades with a minimum blade height are desirable to cut the cost of Eloxing.

   (f) The discs constituting the rotor should be assembled with a sufficiently high bolt tension so that static friction will suffice to resist the output torque, or splines should be employed.

8. Turbine Efficiency

   The Reynolds number should be above 10^5

$$R_e = \frac{12\ W}{\mu\ r_m}$$

Table 2. (continued)

W = flow, lb/sec, μ viscosity, lb/sec·ft
r_m = mean radius, ft

Table 3. Bases for the Thermodynamic and Aerodynamic Design Procedures for a Series of Turbines Meeting the Design Precepts of Table 2

1. Baljé's analysis and charts[15] provide a good basis for estimating the proportions and efficiency of turbine stages.
2. The turbine efficiency is not very sensitive to the adiabatic head distribution between the stages for a given number of stages. The turbine efficiency will not be much less than optimum if the adiabatic head drop per stage is kept uniform. (It can be deduced from Figs. 4 and 5 that the ideal stage efficiency can be increased somewhat by progressively increasing the head per stage from the inlet to the outlet.)
3. The erosion-limited tip speed may favor increasing the head drop across the last stage and reducing the rotor diameter.
4. A larger than average head drop in the early stages will reduce the losses stemming from flow bypassing through the labyrinth seals.
5. The maximum efficiency for a given adiabatic head for a particular stage is given by the maximum efficiency for a given specific speed. To facilitate interpolation, a curve defining this relation was obtained by cross-plotting the minimum specific speeds for each of the constant efficiency curves of Baljé's charts in Figs. 4 and 5 to give the curves of Fig. 6 for full admission turbines. Curves for D_s, H_{ad}, D, and U for some typical values of N and V_3 were also plotted on the same sheet.
6. To reduce the tip speed in the last stage it may be desirable to reduce D_s somewhat from the value for maximum efficiency implied by the extreme right-hand point of the constant efficiency curves of Baljé's charts in Figs. 4 and 5.
7. The velocity energy in the stream leaving any stage except the last stage will be available in the subsequent stage, hence the performance curves of Fig. 5 are applicable. The velocity energy in the stream leaving the last stage will be lost to the exhaust, hence the curves of Fig. 4 will apply for the last stage.
8. The bypass flow through labyrinth seals can be estimated from Fig. 9.
9. The loss associated with the leakage flow from the first-stage rotor cavity toward the adjacent bearing can be reduced by bleeding off vapor at intervals through the labyrinth seal at the pressures corresponding to those at the outlets of the various turbine stages. This vapor would be directed to the appropriate stage in the regenerative feed heater, thus reducing the interstage bleed requirements.

Table 4. Summary of Thermodynamic Calculations for a Series of Ideal Rankine Cycles

T_o/T_c	Fluid	h_o	h_1	h_2	Δh_{is}	Δh_b	$\eta=\Delta h_{is}/\Delta h_b$
2150/1330	Cs	320	258	97.75	62	222.25	27.9
	K		981	341.4	249.5	889.1	28.1
2150/1200	Cs	320	245.7	91.9	74.3	228.1	32.55
	K	1230.5	932	321.9	298.6	908.6	32.85
2000/1200	Cs	316.9	251	91.9	65.9	225	29.3
	K	1222.5	964	321.9	258.5	900.6	28.7
2000/1330	Cs	316.9	263.6	97.75	53.3	219.15	24.3
	K	1222.5	1012.5	341.4	210	881.1	23.85
2000/1040	Cs	316.9	235.6	81	81.3	235.9	34.5
	K	1222.5	900	286.1	322.5	936.4	34.4
2150/1040	Cs	320	230	81	90	239	37.65
	K	1230.5	873	286.1	357.5	944.4	37.9
2150/1125	Cs	320	238.8	86	81.2	234	34.7
2150/1140	K	1230.5	912.2	304.8	318.3	925.7	34.4
2150/1250	Cs	320	250.5	93.7	69.5	226.3	30.7
2150/1240	K	1230.5	949	323.8	281.5	906.7	31.05
2000/1125	Cs	316.9	243.9	86	73	230.9	31.6
2000/1140	K	1222.5	938	203.8	284.5	917.7	31.0
2000/1250	Cs	316.9	265.1	93.7	60.8	223.2	27.25
2000/1240	K	1222.5	977	323.8	245.4	898.7	27.3

FOLDOUT FRAME /

Table 5. Thermodynamic Calc

① Stage No.	② Temperature (°F)	③ P (psia)	④ V_s (ft^3/lb)	⑤ S_{ad} (entropy)	⑥ Vapor Quality Isentropic %	⑦ Vapor Quality Assumed η %	⑧ h_{is} (enthalpy)	⑨ h_{ad} $⑨_{n-1}$ - ⑫
0	2150	314.6	.525	.3205	100	100	320	320
1	1740	114.5	1.3065	.3238	89	93	291.4	298.6
2	1330	23.6	5.5691	.3286	79.1	83.1	264	272.6
0	2150	314.6	.525	.3205	100	100	320	320
1	1880	172.2	.9001	.3225	93.5	96	302.0	306.5
2	1610	74.4	1.9375	.3250	87.2	89.8	285.2	290.5
3	1330	23.6	5.5691	.3285	78.3	83.0	266.2	272.3
0	2150	314.6	.525	.3205	100	100	320	320
1	1990	229.3	.6923	.3215	97	98.4	310.0	312.5
2	1820	145.5	1.0498	.3230	93	94.6	300.1	303.2
3	1660	88.4	1.6549	.3246	89.3	91.1	290.6	293.8
4	1500	49.4	2.8250	.3263	85.7	87.4	280.3	283.7
5	1330	23.6	5.5691	.3285	81.5	83	268.5	272.3
0	2150	314.6	.525	.3205	100	100	320	320
1	1830	149.7	1.0226	.3229	92	94.8	298.2	303.6
2	1520	53.4	2.6291	.3260	84.5	87.5	278.7	284.9
3	1200	12.11	10.316	.3306	76.8	80.3	255.0	262.5
0	2000	220.4	.731	.3237	100	100	316.88	316.88
1	1780	129.4	1.1687	.3254	94.2	96.2	301.7	305.5
2	1550	59.9	2.3671	.3279	88.0	90.8	286.6	291.3
3	1330	23.6	5.5691	.3380	82.8	85.3	271.3	276.3
0	2000	220.4	.731	.3237	100	100	316.88	316.88
1	1730	111.0	1.3443	.32595	92.4	95.1	297.8	302.6
2	1470	43.8	3.1557	.3287	86.2	88.8	280.8	286.2
3	1200	12.1	10.316	.3327	78.6	82	259.4	266.1

FOLDOUT FRAME 2

amic Calculations for Cesium Vapor Cycles with Bleed-Off for Regenerative Feed Heating

9	10	11	12	13	14	15	16	17	18	19
h_{ad} $9_{n-1} - 12$	Δh_{is} $9_{n-1} - 8_n$	η	Δh_{ad} 10 11	H_{ad} 778 10	C_o $\sqrt{64.34 \; 13}$	T_ℓ	h_ℓ (Btu/lb)	Δh_ℓ (Btu/lb)	h_{vapor} (Btu/lb)	Vapor Bleed Fraction (%)
320		.75								
298.6	28.6		21.45	22,251	1196.5	1652	124.62		187.46	
272.6	34.6		25.95	26,919	1316.0	1300	99.75	24.87	207.20	12.0
	63.2		Σ 47.4							
320										
306.5	18		13.5	14,004	949.2	1814	133.09		180.81	
290.5	21.3		15.975	16,571	1032.6	1548	116.79	16.3	193.66	8.42
272.3	24.3		18.225	18,905	1079.0	1300	99.75	17.04	207.20	8.22
	63.6		Σ 47.7							
320										
312.5	10		7.5	7,780	707.5	1950	139.99		175.32	
303.2	12.4		9.3	9,647	787.8	1790	129.43	9.95	183.68	5.42
293.8	12.6		9.45	9,803	794.2	1628	119.81	9.63	191.25	5.04
283.7	13.5		10.125	10,503	822.0	1460	110.12	10.29	199.01	5.17
272.3	15.2		11.4	11,826	872.3	1300	99.75	10.37	207.20	5.00
	63.7		Σ 47.775							
320										
303.6	21.8		16.35	16,960	1044.6	1762	130.04		183.20	
284.9	24.9		18.675	19,372	1116.4	1450	111.34	19.31	198.03	9.75
262.5	29.9		22.425	23,262	1223.4	1170	91.90	19.44	213.14	9.12
	76.6		57.45							
316.88										
305.5	15.18		11.385	11,810	871.7	1726	127.02		185.44	
291.3	18.9		14.175	14,704	972.6	1508	113.16	13.25	196.57	6.74
276.3	20.0		15.0	15,560	1000.6	1300	99.75	14.02	207.20	6.77
	54.08		40.56							
316.88										
302.6	19.08		14.31	14,844	977.3	1674	124.02		187.93	
286.2	21.8		16.35	16,960	1044.6	1410	108.29	16.33	200.46	8.15
266.1	26.8		20.1	20,850	1158.2	1170	91.90	16.39	213.14	7.69
	67.68		50.76							

FOLDOUT FRAME 3

8	19	20	21	22	23
por (/lb)	Vapor Bleed Fraction (%)	Flow Fraction into Stage	Turbine Δh		
.46		1.00		28.6	
.20	12.0	.88	47.4	30.45	
				59.05	6.6
.81		1.00		18.0	
.66	8.[illegible]2	.916		19.51	
.20	8.22	.834	47.7	20.27	
				57.78	6.6
32		1.00		10.00	
68	5.42	.946		11.72	
25	5.04	.895		11.27	
01	5.17	.844		11.39	
20	5.00	.794	47.7	12.07	
				56.47	6.6
20		1.00		21.8	
03	9.75	.902		22.46	
14	9.12	.811	57.5	24.25	
				68.51	5.6
44		1.00		15.18	
57	6.74	.933		17.63	
20	6.77	.865	40.58	17.3	
				50.11	7.5
93		1.00		19.08	
46	8.15	.918		20.01	
4	7.69	.842	50.78	22.57	
				61.66	6.0

FOLDOUT FRAME 1

Table 6. Thermodynamic Calculations for Potassium Vapor Cycles with Bl

①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬
Stage No.	Temperature (°F)	P (psia)	Vs (ft^3/lb)	s_{ad} (entropy)	Vapor Quality* Isentropic (%)	Vapor Quality* Assumed η (%)	h_{is} (enthalpy)	h_{ad} ⑨$_{n-1}$ - ⑫	Δh_{is} ⑨$_{n-1}$ - ⑧$_n$	η	Δh_{ad} ⑩⑪	H_{ad} 778 ⑩
0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5		.75		
1	1990	148.0	3.82	1.0195	96.5	98.1	1191	1200.9	39.5		29.625	30,731
2	1820	87.0	6.20	1.025	92.8	94.3	1152	1164.2	48.9		36.675	38,044
3	1660	48.6	10.56	1.031	89.0	90.4	1112.5	1125.4	51.7		38.775	40,223
4	1500	24.7	19.74	1.038	84.7	86.3	1068	1082.4	57.4		43.05	44,657
5	1330	10.4	43.74	1.047	80.3	82.2	1021.3	1036.6	61.1		45.825	47,536
									258.6		193.95	
0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5				
1	2035	169.0	3.40	1.0170	98	98.8	1203	1209.9	27.5		20.625	21,395
2	1920	120.5	4.62	1.0203	95.2	96.3	1177.5	1185.6	32.4		24.3	25,207
3	1800	81.3	6.60	1.025	92.1	93.5	1147	1156.6	38.6		28.95	30,031
4	1680	52.5	10.56	1.029	90.0	91.2	1119	1128.4	37.6		28.2	29,253
5	1570	33.9	14.84	1.033	86.9	88.2	1090.2	1099.8	38.2		28.65	29,720
6	1450	19.4	24.58	1.039	83.8	85.1	1055	1066.2	44.8		33.6	34,854
7	1330	10.4	43.74	1.044	80.6	81.8	1022.0	1033.1	44.2		33.15	34,388
									263.3		197.48	
0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5				
1	2060	180.0	3.19	1.017	98.7	99.3	1209	1214.4	21.5		16.125	16,727
2	1970	139.9	4.03	1.020	96.5	97.5	1188.5	1195	25.9		19.425	20,[illegible]
3	1880	106.4	5.49	1.0225	94.6	95.6	1169	1175.5	26.0		19.5	20,[illegible]
4	1790	78.3	6.82	1.026	92.2	93.6	1146	1153.4	29.5		22.125	22,951
5	1700	56.7	9.17	1.029	90.5	91.3	1127	1133.6	26.4		19.8	20,539
6	1600	38.2	13.19	1.033	88	89	1101	1109.2	32.6		24.45	25,363
7	1510	26.2	18.94	1.037	85.6	86.6	1077	1085	32.2		24.15	25,052
8	1425	17.3	27.53	1.041	83.7	84.5	1055.5	1062.9	29.5		22.125	22,951
9	1330	10.4	43.74	1.046	81.1	82.1	1027	1036	35.9		26.925	27,930
									259.5		194.625	
0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5				
1	1960	135.5	4.14	1.0205	95.4	97.3	1180	1192.6	50.5		37.875	39,289
2	1770	73.2	7.26	1.026	91.0	92.9	1135	1149.4	57.6		43.2	44,813
3	1580	35.4	14.25	1.035	86.8	88.5	1091	1105.6	58.4		43.8	45,435
4	1390	14.5	32.47	1.044	81.9	83.9	1038	1054.9	67.6		50.7	52,593
5	1200	4.8	89.85	1.055	76.8	79.1	981	999.5	73.9		55.425	57,494
									308		231.00	
0	2000	141.6	4.03	1.0315	100	100	1222.5	1222.5		.75		
1	1870	103.0	5.33	1.035	97.5	98.7	1190	1198.1	32.5		24.375	25,285
2	1735	64.5	8.14	1.040	94.2	95.5	1157.5	1167.6	40.6		30.45	31,587
3	1600	38.2	13.19	1.046	90.7	92	1122.5	1133.8	45.1		33.825	35,088
4	1465	21.0	22.00	1.0525	87	88.4	1085	1097.2	48.8		36.6	37,966
5	1330	10.4	43.74	1.0595	83.6	85.0	1048	1060.3	49.2		36.9	38,278
									216.2		162.15	
0	2000	141.6	4.03	1.0315	100	100	1222.5	1222.5				
1	1840	93.3	5.83	1.0365	96.5	98.0	1182	1192.1	40.5		30.375	31,509
2	1680	52.5	10.56	1.0425	92.5	94.3	1143	1155.3	49.1		36.825	38,200
3	1520	27.3	18.14	1.0505	88.4	90.2	1101	1114.6	54.3		40.725	42,245
4	1360	12.3	37.53	1.0590	84	85.8	1053	1068.4	61.6		46.2	47,925
5	1200	4.8	89.85	1.066	79.8	81.7	1006	1021.6	62.4		46.8	48,547
									267.9		200.925	
0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5				
1	1990	148	3.82	1.018	96.7	97.7	1191	1198.9	39.5	.801	31.6395	30,731
2	1820	87	6.20	1.023	92.2	93.7	1147.5	1157.8	51.4	.799	41.0686	39,982
3	1660	48.6	10.56	1.027	88.0	89.2	1105	1114.6	52.8	.818	43.1904	41,078
4	1500	24.7	19.74	1.032	84.0	85.2	1063	1071.5	51.6	.835	43.086	40,145
5	1330	10.4	43.74	1.0375	78.9	80.2	1008.5	1019.6	63.0	.824	51.912	49,014
									258.3		210.8965	

FOLDOUT FRAME 2

· Cycles with Bleed-Off for Regenerative Feed Heating

13	14	15	16	17	18	19	20	21
H_{ad} 778 (10)	C_c $\sqrt{6434 (13)}$	T_ℓ	h_ℓ (Btu/lb)	Δh_ℓ (Btu/lb)	h_{vapor} (Btu/lb)	Vapor Bleed Fraction (%)	Flow Fraction into Stage	Turbine Δh
			510.57					
30,731	1406.1	1948	478.39	32.18	738.38	4.35	1.00	
38,044	1564.5	1780	444.01	34.38	763.44	4.50	.955	
40,223	1608.7	1620	412.44	31.57	787.45	4.01	.915	
44,657	1695.1	1460	381.05	31.39	812.35	3.86	.876	
47,536	1748.8	1300	347.33	33.72	838.81	4.02	.836	173.0
			510.57					
21,395	1173.3	2006	487.51	23.06	731.69	3.15	1.00	
25,207	1273.5	1894	464.17	23.34	748.72	3.12	.969	
30,031	1390.0	1792	440.02	24.15	766.40	3.15	.937	
29,253	1371.9	1652	412.44	27.58	784.40	3.52	.902	
29,720	1382.8	1540	394.82	17.62	801.38	2.20	.880	
34,854	1497.5	1420	371.14	23.68	820.21	2.89	.851	
34,386	1487.5	1300	347.33	23.81	838.81	2.84	.823	191.8
			510.57					
16,727	1037.4	2037	492.56	18.01	727.95	2.47	1.00	
20,150	1138.6	1947	474.32	18.24	741.34	2.46	.975	
20,228	1140.8	1857	456.07	18.25	754.60	2.42	.951	
22,951	1215.2	1767	438.03	18.04	767.88	2.35	.928	
20,539	1149.6	1675	420.27	17.76	781.37	2.27	.905	
25,363	1277.4	1578	400.70	19.57	796.70	2.46	.880	
25,052	1269.6	1488	383.02	17.68	810.78	2.18	.856	
22,951	1215.2	1400	366.18	16.84	824.14	2.04	.838	
27,930	1340.5	1300	347.33	18.85	838.81	2.25	.816	193.4
			510.57					
39,289	1589.9	1914	472.29	38.28	742.82	5.15	1.00	
44,813	1698.0	1722	434.06	38.23	770.86	4.96	.950	
45,435	1709.8	1530	396.78	37.28	799.81	4.66	.904	
52,593	1839.5	1346	359.23	37.55	829.59	4.53	.858	
57,494	1923.3	1170	321.90	37.33	857.89	4.35	.815	206.5
			480.42					
25,285	1275.5	1840	454.06	26.36	756.07	3.48	1.00	
31,587	1425.6	1720	427.16	26.90	776.09	3.47	.965	
35,088	1502.5	1566	400.70	26.46	796.70	3.32	.932	
37,966	1562.9	1432	374.12	26.58	817.86	3.25	.890	
38,278	1569.3	1300	347.33	26.79	838.81	3.19	.868	162.2
			480.42					
31,509	1423.8	1800	448.02	32.40	760.49	4.26	1.00	
38,200	1567.7	1640	412.44	35.58	784.40	4.54	.955	
42,245	1648.6	1480	384.99	27.45	809.21	3.39	.921	
47,925	1756.0	1322	353.27	31.72	834.22	3.80	.883	
48,547	1767.3	1170	321.90	31.37	857.89	3.66	.846	200.9
			510.57					
30,731	1406.1	1948	478.39	32.18	738.38	4.35	1.00	
39,982	1603.9	1780	444.01	34.38	763.44	4.50	.955	
41,078	1625.7	1620	412.44	31.57	787.45	4.01	.915	
40,145	1607.1	1460	381.05	31.39	812.35	3.86	.876	
49,014	1775.8	1300	347.33	33.72	838.81	4.02	.836	210.9

Table 7. .Factors Affecting Turbine Efficiency

Volume flow rate
Density of working fluid
Viscosity of working fluid
Thermodynamic properties of working fluid
RPM
Rotor diameter
Blade height
Blade inlet angle
Blade exit angle
Blade chord
Blade pitch
Blade profile (airfoil shape)
Blade twist
Tip clearance
Sonic velocity
Inlet nozzle angle
Number of stages
Head per stage
Head distribution (between stages)
Diameter distribution
Degree of reaction
Fraction admission
Labyrinth seal diameter
Labyrinth seal clearance
Number of lands in labyrinth seals

Table 8. Leakage Flow Through 12-Land Labyrinth Seals for 3.25-in.-diam Straight Journals with a Radial Clearance of 0.0055 in. (Based on Ref. 13)

$$G = A\alpha\Phi\gamma\sqrt{\frac{gp_o}{v_o}} = 0.00039 \times 1.0 \times 0.24 \times 2.2 \times 5.67\sqrt{\frac{p_o}{v_o}}$$

$$= 0.00117\sqrt{\frac{p_o}{v_o}} \text{ (for } p_o \text{ in lb/ft}^2\text{)}$$

$$= 0.014\sqrt{\frac{p_o}{v_o}} \quad \text{(for } p_o \text{ in psia)}$$

Pressure ahead of seal, psia	250	100	30
Pressure ratio across seal	0.5	0.5	0.5
Inlet specific volume of potassium, ft^3/lb	2.35	5.5	16.2
Potassium leakage flow rate, lb/sec	0.145	0.060	0.019
Potassium temperature, °F	2190	1865	1545
Cesium temperature, °F	2030	1705	1388
Cesium specific volume, ft^3/lb	0.627	1.45	4.35
Cesium flow rate, lb/sec	0.28	0.116	0.0368

Table 9. Summary of Design Conditions for Parametric Calculations of the Efficiency and Proportions of Cesium and Potassium Turbines

Calculation Number	Fluid	Number of stages	T_{inlet}	$T_{cond.}$	RPM
1	Cesium	2	2150	1330	18,000
2	Cesium	3	2150	1330	18,000
3	Cesium	5	2150	1300	18,000
4	Cesium	3	2150	1200	18,000
5	Cesium	3	2000	1300	18,000
6	Cesium	3	2000	1200	18,000
7	Cesium	2	2150	1330	14,400
8	Cesium	3	2150	1330	14,400
9	Cesium	5	2150	1330	14,400
10	Cesium	2	2150	1330	24,000
11	Cesium	3	2150	1330	24,000
12	Cesium	5	2150	1330	24,000
13	Potassium	5	2150	1330	24,000
14	Potassium	7	2150	1330	24,000
15	Potassium	9	2150	1330	24,000
16	Potassium	5	2150	1200	24,000
17	Potassium	5	2000	1330	24,000
18	Potassium	5	2000	1200	24,000
19	Potassium	5	2150	1330	18,000
20	Potassium	5	2150	1330	24,000
21	Cesium	1	2150	1330	24,000
22	Cesium	3	2150	1330	18,000

FOLDOUT FRAME 1

25	26	27	28	29	30	31	32	33	34	35	36	37	38	
Flow, $\dot{w}$ (lb/sec)	N (rpm)	Stage No.	Ps (psia)	No. Lands in Seal	Seal Leakage (lb/sec)	V'_s (ft³/sec)	H_{ad} (ft-lb/lb)	N_s	η (%)	D_s	$H_{ad}^{1/4}$	$V'^{1/2}_s$	Rotor Diam (ft)	Tur Tip (ft/
						$\frac{(4)(7)}{100\,(28)}\left(1-\frac{(30)}{(25)}\right)$		$\frac{(26)\sqrt{(31)}}{(32)^{.75}}$			$(32)^{.25}$	$\sqrt{(31)}$	$\frac{(35)(37)}{(36)}$	$.0523598\,(26)(38)$
7.9	18,000	1	114.5	12	-0-	9.5985	22,251	30.64	81.8	1.83	12.2134	3.0981	.464	467
(2150°F-1330°F)		2	23.6		.33	30.8296	26,919	47.56	82.2	1.55	12.8090	5.5524	.672	676
		1	172.2		-0-	6.8264	14,004	36.53	83.3	1.60	10.8783	2.6127	.384	384
		2	74.4		.43	11.9049	16,571	42.52	84.4	1.43	11.3459	3.4503	.435	424
		3	23.6		.20	29.6835	18,905	60.83	82.5	1.28	11.7258	5.4483	.595	595
		1	229.3		-0-	5.3815	7780	50.41	85.5	1.25	9.3917	2.3198	.309	309
		2	145.5		.59	6.8677	9647	48.46	85.3	1.29	9.9106	2.6206	.341	340
		3	88.4		.34	10.2007	9803	58.35	86.3	1.14	9.9504	3.1939	.366	365
		4	49.4		.224	15.9960	10,503	69.39	86.9	1.04	10.1234	3.9995	.411	410
		5	23.6		.128	28.5240	11,826	84.77	78.3	.93	10.4282	5.3408	.476	475
6.7		1	149.7		-0-	6.4950	16,960	30.87	81.9	1.83	11.4119	2.5485	.409	417
(2150°F-1200°F)		2	53.4		.398	13.0767	19,372	39.64	83.9	1.50	11.7976	3.6162	.460	469
		3	12.11		.152	43.9901	23,262	63.38	82.4	1.24	12.3499	6.6325	.666	679
9.0		1	129.4		-0-	10.1187	11,810	50.54	85.5	1.25	10.4247	3.1810	.381	376
(2000°F-1330°F)		2	59.9		.320	17.4060	14,704	56.24	86.1	1.17	11.0118	4.1720	.443	437
		3	23.6		.165	36.3039	15,560	77.85	80.2	1.02	11.1687	6.0253	.550	543
7.2		1	111.0		-0-	9.2045	14,844	40.61	84.0	1.49	11.0379	3.0339	.410	417
(2000°F-1200°F)		2	43.8		.296	17.7605	16,960	31.04	85.6	1.25	11.4119	4.2143	.462	470
		3	12.1		.124	50.3995	20,850	73.65	81.1	1.08	12.0165	7.0993	.638	650
7.9	24,000	1	114.5	12	-0-	9.5985	22,251	40.81	84.1	1.48	12.2134	3.0981	.375	500
(2150°F-1330°F)		2	23.6		.33	30.8296	26,919	63.41	82.4	1.24	12.8090	5.5524	.538	718
		1	172.2		-0-	6.8264	14,004	48.71	85.3	1.30	10.8783	2.6127	.312	415
		2	74.4		.43	11.9049	16,571	56.70	86.1	1.16	11.3459	3.4503	.353	470
		3	23.6		.20	29.6835	18,905	81.10	79.4	.98	11.7258	5.4483	.455	605
		1	229.3		-0-	5.3815	7780	67.21	87.4	1.05	9.3917	2.3198	.259	352
		2	145.5		.59	6.8677	9647	64.61	86.7	1.08	9.9106	2.6206	.286	388
		3	88.4		.34	10.2007	9803	77.80	87.2	.98	9.9504	3.1939	.315	427
		4	49.4		.224	15.9960	10,503	92.52	87.4	.92	10.1234	3.9995	.363	493
		5	23.6		.128	28.5240	11,826	113.03	56.0	.74	10.4282	5.3408	.379	516
7.9	14,400	1	114.5	12	-0-	9.5985	22,251	24.49	79.9	2.20	12.2134	3.0981	.558	455
(2150°F-1330°F)		2	23.6		.33	30.8296	26,919	38.05	80.4	1.79	12.8090	5.5524	.776	632
		1	172.2	12	-0-	6.8264	14,004	29.23	81.4	1.90	10.8783	2.6127	.456	368
		2	74.4		.43	11.9049	16,571	34.02	82.7	1.68	11.3459	3.4503	.511	412
		3	23.6		.20	29.6835	18,905	48.66	82.2	1.52	11.7258	5.4483	.706	570
		1	229.3	12	-0-	5.3815	7780	40.32	84.0	1.49	9.3917	2.3198	.368	295
		2	145.5		.59	6.8677	9647	38.77	83.7	1.53	9.9106	2.6206	.405	324
		3	88.4		.34	10.2007	9803	46.68	85.0	1.33	9.9504	3.1939	.427	342
		4	49.4		.224	15.9960	10,503	55.51	86.1	1.18	10.1234	3.9995	.466	373
		5	23.6		.128	28.5240	11,826	67.82	81.9	1.17	10.4282	5.3408	.599	480
9.0	24,000	1	214	0	-0-	34	48,236	43.0	81.5	1.67	14.8198	5.8310	.657	805
7.5	18,000	1	172.2	12	-0-	6.4808	14,004	35.60	83.1	1.63	10.8783	2.5457	.381	390
(2150°F-1330°F)		2	74.4		.43	11.2675	16,571	41.37	84.2	1.46	11.3459	3.3567	.432	442
		3	23.6		.20	28.1415	18,983	59.04	82.5	1.31	11.7379	5.3049	.592	606

FOLDOUT FRAME 2

Table 10. Aerodynamic Calculations for Cesium

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
$V'^{1/2}_s$	Rotor Diam (ft)	Turbine Tip Speed (ft/sec)	Moisture Assumed η	Δh_{is}	Net In-Flow Fraction	Δh_{boiler}	Δh_{boiler} (No Bleed)	h/D	$\eta\ \Delta h_{is}$	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	Σ (Net Stage Output)	η_c (%)	Power (kwe)
$\sqrt{(31)}$	$\frac{(35)(37)}{(39)}$	$\frac{.0523598\,(20)(35)}{12}$	$1-(7)$	(10)	(20)	$(8)_o-(16)_1$	$(8)_o-(16)_n$	Figure 7	(34)(41)	1.25 (40)	$(42)\left(1-\frac{(40)}{4}\right)(38)(27)$	$(46)(48)\left(\frac{100-(47)}{100}\right)$	$\Sigma(49)$	$\frac{(50)}{(43)}$	.949311 (25)(50)
3.0981	.464	467	.07	28.6	1.00	195.38	195.38	.0540	23.39	8.75	.9825	2097			
5.5524	.672	676	.169	34.6	.88		220.25	.0664	28.44	21.125	.8010	1797	38.94	19.93 (17.94)	292.03
2.6127	.384	384	.04	18	1.00	186.91	186.91	.0653	14.99	5.0	.9900	1410			
3.4503	.435	424	.102	21.3	.916		203.21	.0764	17.98	12.75	.8382	1315			
5.4483	.592	595	.170	24.3	.834		220.25	.0873	20.05	21.25	.7732	1221	39.46	21.11 (19.00)	295.93
2.3198	.309	309	.016	10	1.00	180.01	180.01	.0922	8.55	2.0	.9970	835			
2.6206	.341	340	.054	12.4	.946	182.8	190.57	.0883	10.58	6.75	.8583	847			
3.1939	.366	365	.089	12.6	.895		200.19	.1046	10.87	11.125	.8320	804			
3.9995	.411	410	.126	13.5	.844		209.88	.1183	11.73	15.75	.7891	780			
5.3408	.476	475	.170	15.2	.794		220.25	.1375	11.90	21.25	.7441	697	39.63	22.02	297.21
2.5485	.409	417	.052	21.8	1.00	189.96	189.96	.0540	17.85	6.5	.9870	1648			
3.6162	.460	469	.125	24.9	.902		208.66	.0715	20.89	15.625	.8144	1436			
6.6325	.666	679	.197	29.9	.811		228.10	.0913	24.64	24.625	.7484	1390	44.74	23.55	284.56
3.1810	.381	376	.038	15.18	1.00	189.86	189.86	.0922	12.98	4.75	.9905	1224			
4.1720	.443	437	.092	18.9	.933		203.72	.1009	16.27	11.50	.8760	1262			
6.0253	.550	543	.147	20.0	.865		227.13	.1207	16.04	18.375	.8149	1067	35.53	18.71 (16.84)	303.56
3.0339	.410	417	.049	19.08	1.00	192.86	192.86	.0721	16.03	6.125	.9878	1486			
4.2143	.462	470	.112	21.8	.918		208.59	.0921	18.66	14.00	.8512	1366			
7.0993	.638	650	.180	26.8	.842		224.98	.1112	21.73	22.50	.7869	1325	41.77	21.66 (19.49)	285.50
3.0981	.375	500	.07	28.6	1.00	195.38	195.38	.0728	2405	8.75	.9825	2156			
5.5524	.538	718	.169	34.6	.88		220.25	.0913	28.51	21.125	.8010	1801	3957	20.25 (18.225)	296.76
2.6127	.312	415	.04	18	1.00	186.91	186.91	.0872	15.35	5.0	.9900	1444			
3.4503	.353	470	.102	21.3	.916		203.21	.1021	18.34	12.75	.8382	1341			
5.4483	.455	605	.170	24.3	.834		220.25	.1277	19.29	21.25	.7732	1175	3960	21.19 (19.071)	296.98
2.3198	.259	352	.016	10	1.00	180.01	180.01	.1169	8.74	2.0	.9960	853			
2.6206	.286	388	.054	12.4	.946		190.57	.1125	10.75	6.75	.8585	861			
3.1939	.315	427	.089	12.6	.895		200.19	.1281	10.99	11.125	.8320	812			
3.9995	.363	493	.126	13.5	.844		209.88	.1389	11.80	15.75	.7891	784			
5.3408	.379	516	.170	15.2	.794		220.25	1.884	8.51	21.25	.7441	499	3809	21.16 (19.04)	285.66
3.0981	.558	455	.07	28.6	1.00	195.38	195.38	.0414	22.85	8.75	.9825	2049			
5.5524	.776	632	.169	34.6	.88		220.25	.0543	27.82	21.125	.8010	1758	38.07	1948 (17.53)	285.51
2.6127	.456	368	.04	18	1.00	186.91	186.91	.0512	14.65	5.0	.9900	1378			
3.4503	.511	412	.102	21.3	.916		203.21	.0610	17.62	12.75	.8382	1288			
5.4483	.706	570	.170	24.3	.834		220.25	.0684	19.97	21.25	.7732	1216	38.82	20.76 (18.68)	291.13
2.3198	.368	295	.016	10	1.00	180.01	180.01	.0722	8.40	2.0	.9960	819			
2.6206	.405	324	.054	12.4	.946		190.57	.0696	10.38	6.75	.8585	831			
3.1939	.427	342	.089	12.6	.895		200.19	.0846	10.71	11.125	.8320	792			
3.9995	.466	373	.126	13.5	.844		209.88	.0997	11.62	15.75	.7891	773			
5.3408	.599	480	.170	15.2	.794		220.25	.0992	12.45	21.25	.7441	729	39.44	21.91 (19.72)	295.78
5.8310	.657	805	.13	62	1.00	220.25	220.25	.0597	50.53	16.25	.9675	4094	40.94	18.59	349.78
2.5457	.381	390	.044	18.0	1.00	186.91	186.91	.0636	14.96	5.50	.9890	1398			
3.3567	.432	442	.104	21.3	.916		203.21	.0742	17.93	13.00	.8348	1303			
5.3049	.592	606	.158	24.4	.834		220.25	.0845	20.13	19.75	.7744	1251	39.52	21.14	281.38

FOLDOUT FRAME 3

49	50	51	52	53	54	55	56	57	58	59	60
Net tage utput	Σ (Net Stage Output)	η_c (%)	Power (kwe)	Rotor Diam (in.)	Blade Height (in.)	Weight Flow Correction	Corrected Rotor Diam	Corrected Blade Height	C_1	B	M
	Σ 49	50 45	.949311 25 50	12 38	12 38 45	333 52	53 55	54 55	31 55² 3.14159 56 57 57 144	144 58 59² 58	59 /(Fig. 45)
097				5.57	.301	1.068374	5.95	.322	259.38	747.50	
797	38.94	19.93	292.03	8.06	.535		8.61	.572	328.37	682.55	.898
		(17.94)									
410				4.61	.301	1.061311	4.89	.319	227.74	583.73	
315				5.22	.399		5.40	.423	275.09	634.06	
221	39.46	21.11	295.93	7.14	.623		7.58	.661	315.74	538.94	.710
		(19.00)									
35				3.71	.342	1.059023	3.93	.362	202.25	420.77	
47				4.09	.361		4.33	.382	221.05	471.22	
04				4.39	.458		4.65	.485	245.13	461.00	
30				4.94	.583		5.22	.617	273.40	456.20	
97	39.63	22.02	297.21	5.71	.785		6.05	.831	319.26	464.06	.610
548				4.91	.265	1.082306	5.31	.287	223.51	643.48	
436				5.52	.395		5.97	.428	273.50	671.59	
390	44.74	23.55	284.56	7.99	.730		8.65	.790	351.45	605.31	.821
224				4.57	.422	1.047888	4.79	.442	252.90	523.37	
262				5.32	.536		5.57	.562	297.05	572.26	
067	35.53	18.71	303.56	6.60	.797		6.92	.835	343.19	524.70	.691
		(16.84)									
486				4.92	.355	1.080523	5.32	.384	240.51	582.24	
366				5.54	.511		5.99	.552	293.04	607.94	
325	41.77	21.66	285.50	7.66	.851		8.28	.920	368.64	580.15	.786
		(19.49)									
156				4.50	.328	1.059826	4.77	.348	303.01	723.96	
301	3957	20.25	296.76	6.46	.589		6.85	.624	385.50	663.70	.88
		(18.225)									
444				3.74	.326	1.059433	3.96	.345	265.80	562.92	
341				4.24	.432		4.49	.458	313.06	601.83	
175	3960	21.19	296.98	5.46	.697		5.78	.738	387.38	558.31	.725
		(19.071)									
3				3.11	.363	1.080221	3.36	.392	229.02	391.41	
1				3.43	.386		3.71	.417	247.63	436.84	
2				3.78	.484		4.08	.523	271.50	419.16	
4				4.36	.605		4.71	.654	298.58	404.48	
9	3809	21.16	285.66	4.55	.857		4.92	.926	381.87	466.68	.613
		(19.04)									
49				6.70	.277	1.080504	7.24	.299	229.06	754.96	
58	38.07	1948	285.51	9.31	.506		10.06	.547	293.43	713.96	.939
		(17.53)									
78				5.47	.280	1.070024	5.85	.300	201.09	594.68	
88				6.13	.374		6.56	.400	236.97	638.63	
16	38.82	20.76	291.13	8.47	.579		9.06	.620	260.97	543.69	.717
		(18.68)									
9				4.42	.319	1.061580	4.69	.339	177.53	428.38	
1				4.86	.338		5.16	.359	193.89	480.43	
2				5.12	.433		5.44	.460	216.67	474.44	
3				5.59	.558		5.93	.592	246.31	479.35	
9	39.44	21.91	295.78	7.19	.713		7.63	.757	266.77	440.48	.580
		(19.72)									
94	40.94	18.59	349.78	7.88	.471	.97572	7.69	.460	457.22	1022	1.35
98				4.57	.291		4.97	.317	219.09	576.80	
03				5.18	.384		5.63	.418	257.89	614.60	
51	39.52	21.14	281.38	7.10	.600	1.08787	7.72	.653	304.08	526.06	.693

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Flow, W (lb/sec)	N (rpm)	Stage No.	P_3 (psia)	No. Lands in Seal	Seal Leakage (lb/sec)	V'_3 (ft^3/sec)	H_{ad} (ft-lb/lb)	N_s	η (%)	D_s	$H_{ad}^{1/4}$	$V'_3{}^{1/2}$	Rotor Diam D (ft)	Turbine Tip Speed U (ft/sec)
					Fig.	$\frac{(20)(4)(7)(25)}{100}\left(1-\frac{(30)}{(25)}\right)$		$(26)\sqrt{(31)}/(32)^{.75}$	Fig.	Fig.	$(32)^{.25}$	$\sqrt{(31)}$	(35)(37)/(36)	0.004363 (26)(56)
1.61	24,000	1	148	12	-0-	6.0333	30,731	25.40	80.1	2.13	13.2402	2.4563	0.3952	599
		2	87		0.178	7.9956	38,044	24.91	79.9	2.17	13.9660	2.8276	0.4394	666
(2150°F to 1330°F)		3	48.6		0.111	13.0935	40,223	30.58	81.8	1.83	14.1618	3.6185	0.4676	709
		4	24.7		0.068	23.0116	44,657	37.48	83.5	1.57	14.5369	4.7970	0.5181	786
		5	10.4		0.038	47.2509	47,536	51.24	82.4	1.46	14.7658	6.8739	0.6797	1031
1.61	24,000	1	169	12	-0-	5.4083	21,395	31.55	82.1	1.80	12.0942	2.3256	0.3461	513
		2	120.5		0.176	6.1821	25,207	29.83	81.6	1.87	12.6003	2.4864	0.3690	548
(2150°F to 1330°F)		3	81.3		0.136	8.5230	30,031	30.71	81.8	1.83	13.1641	2.9194	0.4058	602
		4	52.5		0.096	13.1520	29,253	38.91	83.7	1.60	13.0780	3.6266	0.4437	658
		5	33.9		0.075	17.6804	29,720	44.58	84.7	1.38	13.1299	4.2048	0.4419	656
		6	19.4		0.047	27.8228	34,854	49.63	85.4	1.28	13.6635	5.2747	0.4941	734
		7	10.4		0.029	46.5548	34,388	64.85	82.2	1.22	13.6176	6.8231	0.6113	908
1.61	24,000	1	180	12	-0-	5.1000	16,727	36.85	83.3	1.60	11.3725	2.2583	0.3177	469
		2	139.9		0.166	5.5320	20,150	33.38	82.5	1.72	11.9143	2.3520	0.3395	501
(2150°F to 1330°F)		3	106.4		0.137	7.3522	20,228	38.37	83.6	1.55	11.9258	2.7115	0.3524	520
		4	78.3		0.108	8.8977	22,951	38.39	83.6	1.55	12.3084	2.9829	0.3756	555
		5	56.7		0.084	11.5623	20,539	47.57	85.2	1.31	11.9714	3.4003	0.3721	550
		6	38.2		0.069	15.9191	25,363	47.65	85.2	1.31	12.6197	3.9899	0.4142	612
		7	26.2		0.047	21.9961	25,052	56.53	86.1	1.16	12.5809	4.6900	0.4324	639
		8	17.3		0.034	30.7230	22,951	71.34	87.1	1.02	12.3084	5.5428	0.4593	678
		9	10.4		0.026	46.4160	27,930	75.68	80.7	1.04	12.9276	6.8129	0.5481	809
1.37	24,000	1	135.5	12	-0-	5.5186	39,289	20.20	78.0	2.59	14.0789	2.3492	0.4322	672
		2	73.2		0.168	7.7016	44,813	21.62	78.6	2.45	14.5496	2.7752	0.4673	727
(2150°F to 1200°F)		3	35.4		0.100	14.4788	45,435	29.35	81.4	1.90	14.5998	3.8051	0.4952	769
		4	14.5		0.052	30.8068	52,593	38.36	83.6	1.55	15.1437	5.5504	0.5678	882
		5	4.8		0.025	77.9067	57,494	57.05	82.6	1.34	15.4848	8.8265	0.7638	1188
1.90	24,000	1	103.0	12	-0-	0.9953	25,285	37.84	83.5	1.56	12.6100	3.1615	0.3911	561
		2	64.5		0.120	13.3528	31,587	37.01	83.4	1.58	13.3314	3.6541	0.4331	622
(2000°F to 1330°F)		3	38.2		0.083	20.5495	35,088	42.44	84.4	1.43	13.6864	4.5332	0.4736	680
		4	21.0		0.053	31.9692	37,966	49.89	85.4	1.27	13.9588	5.6541	0.5144	738
		5	10.4		0.033	60.2507	38,278	68.07	81.9	1.15	13.9874	7.7621	0.6382	916
1.55	24,000	1	93.3	12	-0-	8.8558	31,509	30.20	81.6	1.85	13.3232	2.9759	0.4132	608
		2	52.5		0.117	13.6278	38,200	32.42	82.3	1.75	13.9803	3.6916	0.4621	680
(2000°F to 1200°F)		3	27.3		0.072	22.2730	42,245	38.44	83.6	1.55	14.3365	4.7194	0.5102	750
		4	12.3		0.042	42.8774	47,925	48.52	85.2	1.29	14.7959	6.5481	0.5709	840
		5	4.8		0.021	94.9550	48,547	71.51	81.3	1.06	14.8436	9.7444	0.6959	1023
1.61	18,000	1	148	12	-0-	6.0333	30,731	19.05	77.5	2.72	13.2402	2.4563	0.5046	583
		2	87		0.178	7.9956	38,044	18.68	77.3	2.76	13.9660	2.8276	0.5588	646
(2150°F to 1330°F)		3	48.6		0.111	13.0935	40,223	22.93	79.1	2.33	14.1618	3.6185	0.5985	687
		4	24.7		0.068	23.0116	44,657	28.11	81.1	1.96	14.5369	4.7970	0.6468	747
		5	10.4		0.038	47.2509	47,536	38.43	80.5	1.78	14.7658	6.8739	0.8286	957
1.61	24,000	1	148	12	-0-	6.0087	30,731	25.35	80.1	2.13	13.2402	2.4513	0.3943	596
		2	87		0.178	7.9447	39,982	23.92	79.6	2.25	14.1405	2.8186	0.4485	678
(2150°F to 1330°F)		3	48.6		0.111	12.9197	41,078	29.90	81.6	1.87	14.2365	3.5944	0.4721	714
		4	24.7		0.068	22.7183	40,145	40.33	84.0	1.48	14.1549	4.7664	0.4984	753
		5	10.4		0.038	46.1011	49,014	49.47	82.3	1.50	14.8792	6.7898	0.6845	1034

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Table 11. Aerodynamic Calculations for Potassium

38	39	40	41	42	43	44	45	46	47	48	49	50	51
Rotor Diam D (ft)	Turbine Tip Speed U (ft/sec)	Moisture Assumed (%)	Δh_{is}	Net In-Flow Fraction	Δh_{boiler}	Δh_{boiler} (no bleed)	h/D	$\eta\ \Delta h_{is}$	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	Σ (Net Stage Output)	η_c (%)
(35) (37) / (36)	0.004363 (26) (56)	1 − (7)/100	(10)	(20)	$(8)_o - (16)_1$	$(8)_o - (16)_n$	Fig. 7	(34) (41)	1.25 (40)	(42) (1 − (40)/4 − (30) (25))	(46) (48) (1 − (47)/100)	Σ (49)	(50) / (43)
0.3952	599	0.035	39.5	1.00	752.11	752.11	0.0434	31.64	4.375	0.99125	29.99		
0.4394	666	0.072	48.9	0.955		786.49	0.0423	39.07	9.00	0.82725	29.41		
0.4676	709	0.110	51.7	0.195		818.06	0.0540	42.29	13.75	0.82089	29.94		
0.5181	786	0.153	57.4	0.876		849.45	0.0671	47.93	19.125	0.80026	31.02		
0.6797	1031	0.197	61.1	0.836		883.17	0.0724	50.35	24.625	0.77122	29.27	149.63	19.89
0.3461	513	0.020	27.5	1.00	742.99	742.99	0.0553	22.58	2.50	0.99500	21.91		
0.3690	548	0.048	32.4	0.969		766.33	0.0524	26.44	6.00	0.84806	21.08		
0.4058	602	0.079	38.6	0.937		790.48	0.0549	31.57	9.875	0.83402	23.73		
0.4437	658	0.100	37.6	0.902		818.06	0.0549	31.47	12.50	0.81982	22.57		
0.4419	656	0.131	38.2	0.880		835.68	0.0803	32.36	16.375	0.80460	21.77		
0.4941	734	0.162	44.8	0.851		859.56	0.0891	38.26	20.25	0.78734	24.02		
0.6113	908	0.194	44.2	0.823		883.17	0.0934	36.33	24.25	0.76507	21.05	156.13	21.01
0.3177	469	0.013	21.5	1.00	737.94	737.94	0.0653	17.91	1.625	0.99675	17.56		
0.3395	501	0.035	25.9	0.975		756.18	0.0590	21.37	4.375	0.86336	17.64		
0.3524	520	0.054	26.0	0.951		774.43	0.0682	21.74	6.75	0.85307	17.29		
0.3756	555	0.078	29.5	0.928		792.47	0.0682	24.66	9.75	0.84282	18.76		
0.3721	550	0.095	26.4	0.905		810.23	0.0864	22.49	11.875	0.83133	16.48		
0.4142	612	0.120	32.6	0.880		829.80	0.0864	27.28	15.0	0.81074	19.14		
0.4324	639	0.144	32.2	0.858		847.48	0.1022	27.72	18.0	0.79792	18.14		
0.4593	678	0.163	29.5	0.838		864.32	0.1215	25.69	20.375	0.78273	16.01		
0.5481	809	0.189	35.9	0.816		883.17	0.1175	28.97	23.625	0.76129	16.84	157.86	21.39
0.4322	672	0.046	50.5	1.00	758.21	758.21	0.0326	39.39	5.75	0.98850	36.70		
0.4673	727	0.090	57.6	0.950		796.44	0.353	45.27	11.25	0.80600	32.38		
0.4952	769	0.132	58.4	0.904		833.72	0.0512	47.54	16.50	0.80118	31.80		
0.5678	882	0.181	67.6	0.858		871.27	0.0682	56.51	22.625	0.78122	34.16		
0.7638	1188	0.232	73.9	0.815		908.60	0.0819	61.04	29.00	0.74948	32.48	167.52	22.09
0.3911	561	0.013	32.5	1.00	768.44	768.44	0.0677	27.14	1.625	0.99675	26.60		
0.4331	622	0.045	40.6	0.965		795.34	0.0665	33.86	5.625	0.89099	28.47		
0.4736	680	0.080	45.1	0.932		821.80	0.0764	38.06	10.00	0.86968	29.79		
0.5144	738	0.116	48.8	0.890		848.38	0.0901	41.68	14.50	0.83630	29.80		
0.6382	916	0.150	49.2	0.868		875.17	0.1019	40.29	18.75	0.81808	26.78	141.44	18.44
0.4132	608	0.020	40.5	1.00	774.48	774.48	0.0532	33.05	2.50	0.99500	32.06		
0.4621	680	0.057	49.1	0.955		810.06	0.0576	40.41	7.125	0.86591	32.50		
0.5102	750	0.098	54.3	0.921		837.51	0.0682	45.39	12.25	0.85198	33.94		
0.5709	840	0.142	61.6	0.883		869.23	0.0883	52.48	17.75	0.82456	35.59		
0.6959	1023	0.183	62.4	0.846		900.60	0.1147	50.73	22.875	0.79375	31.06	165.15	21.32
0.5046	583	0.035	39.5	1.00	752.11	752.11	0.0303	30.61	4.375	0.99125	29.02		
0.5588	646	0.072	48.9	0.955		786.49	0.0296	37.80	9.00	0.82725	28.46		
0.5985	687	0.110	51.7	0.915		818.06	0.0381	40.89	13.75	0.82089	28.95		
0.6468	747	0.153	57.4	0.876		849.45	0.0490	46.55	19.125	0.80026	30.13		
0.8286	957	0.197	61.1	0.836		883.17	0.0547	49.18	24.625	0.77122	28.59	145.15	19.30
0.3943	596	0.023	39.5	1.00	752.11	752.11	0.0434	31.64	2.875	0.99425	30.55		
0.4485	678	0.063	51.4	0.955		786.49	0.0401	40.91	7.875	0.82940	31.26		
0.4721	714	0.108	52.8	0.915		818.06	0.0524	43.08	13.500	0.82135	30.61		
0.4984	753	0.148	51.6	0.876		849.45	0.0729	43.34	18.500	0.80135	28.31		
0.6845	1034	0.198	63.0	0.836		883.17	0.0697	51.85	24.750	0.77102	30.08	150.81	20.05

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49	50	51	52	55	56	57	58	59	60
Net Stage Output	Σ (Net Stage Output)	η_c (%)	Power (kwe)	Weight Flow Correction	Corrected Rotor Diameter (in.)	Corrected Blade Height (in.)	Axial Velocity (ft/sec)	Relative Velocity Entering Turbine (ft/sec)	Relative Mach No. Entering Turbine
$(46)(48)\left(1 - \frac{(47)}{100}\right)$	$\Sigma\,(49)$	$(50)/(43)$	$0.9493\,(25)(50)$	$\sqrt{\frac{333}{(52)}}$	$12\,(38)\,55$	$(45)(56)$	$\frac{(31)(55)^2\,144}{\pi((56)-(57))(57)}$	$\sqrt{(\sqrt{(11)^2-(58)^2}-(38))^2+(58)^2}$	$(59)/(\text{Fig. }45)$
9.99				1.206698	5.72	0.249	244.96	822.91	
9.41					6.36	0.269	269.91	915.72	
9.94				(R)	6.77	0.366	308.98	923.00	
1.02					7.51	0.503	361.13	942.15	
9.27	149.63	19.89	228.69		9.85	0.713	401.17	781.92	.544
1.91				1.181298	4.90	0.272	232.63	678.15	
1.08					5.23	0.274	246.51	743.47	
3.73					5.75	0.311	272.83	808.39	
2.57					6.28	0.409	296.57	743.20	
1.77					6.26	0.503	330.60	762.14	
4.02					7.01	0.624	378.06	808.79	
1.05	156.13	21.01	238.63		8.67	0.809	396.38	658.41	.457
7.56				1.174818	4.48	0.298	223.86	588.22	
7.64					4.78	0.282	234.85	656.56	
7.29					4.97	0.338	252.88	644.13	
8.76					5.30	0.361	268.73	685.02	
6.48					5.25	0.453	286.52	632.00	
9.14					5.84	0.504	318.75	701.58	
8.14					6.10	0.623	347.14	677.85	
6.01					6.47	0.787	369.91	605.63	
6.84	157.86	21.39	241.27		7.73	0.908	403.51	618.94	.419
6.70				1.236299	6.42	0.208	242.03	931.37	
2.38					6.94	0.245	266.07	986.58	
1.80					7.34	0.376	313.34	964.18	
4.16					8.42	0.575	387.01	994.70	
2.48	167.52	22.09	217.87		11.34	0.928	456.91	819.45	.585
6.60				1.142506	5.36	0.363	288.57	740.01	
8.47					5.94	0.395	319.26	831.15	
.79					6.49	0.496	361.97	858.31	
9.80					7.05	0.635	410.99	872.72	
6.78	141.44	18.44	255.11		8.75	0.891	450.60	740.18	.514
2.06				1.170604	5.81	0.309	279.54	836.20	
2.50					6.50	0.373	319.96	912.63	
8.94					7.16	0.489	366.35	932.37	
.59					8.02	0.708	444.41	967.00	
.06	165.15	21.32	243.01		9.77	1.121	525.50	847.07	.606
.02				1.225159	7.42	0.224	210.19	834.21	
.46					8.22	0.243	231.64	930.55	
.95					8.75	0.333	262.34	937.61	
.13					9.51	0.466	306.62	969.88	
.59	145.15	19.30	221.85		12.18	0.666	346.03	832.54	.578
.55				1.201951	5.69	0.246	247.19	826.05	
.26					6.47	0.260	271.09	942.64	
.61					6.82	0.357	308.50	934.55	
.31					7.19	0.524	358.33	889.05	
.08	150.81	20.05	230.50		9.87	0.689	401.52	803.35	.558

Table 12. Procedure for Turbine Aerodynamic Design Hand Calculations

1. Specify the number of stages, assume a 100% nozzle efficiency, and overall stage efficiencies. Allocate the pressure distribution and calculate the head drop per stage using a Mollier diagram. This procedure also specifies P_3 and V_3 for each stage. (Typical calculations are summarized in Table 5.)
2. Neglecting heat losses to the surroundings, use a heat balance to calculate the ideal bleed flows to the regenerative feed heater assuming a heating effectiveness of 0.80 for each feed heater stage. (Typical calculations are summarized in Table 5.)
3. Specify the rpm.
4. Determine N_s for each point and enter in Table 10.
5. Find the values for η and D_s from Fig. 6.
6. Determine $H_{ad}^{1/4}$ and calculate $V_3^{1/2}$ and D.
7. Calculate the tip speed, U. ($U = 2\ \pi DN/60$).
8. Values for h/d can be found in Fig. 9.
9. Using the above calculated value for turbine efficiency and the isentropic enthalpy drop of Table 5 or 6, calculate the enthalpy drop per stage.
10. Estimate the leakage through that seal from Fig. 9.
11. Calculate the fraction of the flow passing through each stator by deducting the seal leakage, the moisture removed (assuming that 25% of the total moisture is removed), and the amounts bled off to the regenerative feed heater.
12. Calculate the moisture churning loss assuming 1.25% loss in turbine efficiency per 1% moisture leaving the stage. (See Fig. 10).
13. Calculate the net output of each stage in Btu per pound by multiplying the enthalpy drop per stage given by Step 9 by the fraction of the flow passing through the stage and the factor given by one minus the churning loss.
14. Sum the net stage outputs to give the total net output of the turbine.
15. Divide the total turbine net output per pound of vapor entering the turbine by the heat added in the boiler per pound of vapor generated to give the gross turbine cycle efficiency. The overall cycle efficiency will be 90% of this as a consequence of feed pump and generator losses.

Table 13. Calculation of the Effects of Number of Stages and RPM on the Size and Performance of Cesium Turbines as Determined from a Computing Machine Program Including Aerodynamic and Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Note that the limitations of the computer printout equipment made it necessary to modify the symbols used. These can be defined as follows using the same format as in the printout reproduced on the following pages:

T1	Turbine inlet temperature, °R
NS	Specific speed
C1	Stator inlet velocity, ft/sec
A1	Stator inlet angle, deg
B2	Rotor inlet angle (relative), deg
UM	Mean peripheral velocity of blade, ft/sec
T3	Stage exit temperature, °R
HT1	Stage inlet enthalpy
DS	Specific diameter
C2	Tangential velocity leaving nozzle, ft/sec
A2	Inlet nozzle angle, deg
W2	Relative velocity into rotor, ft/sec
UTIP	Rotor tip speed, ft/sec
HT3	Stage exit enthalpy
S1	Stage inlet entropy
CO	Nozzle discharge velocity, ft/sec
C3	Stage exit velocity, ft/sec
A3	Stage exit angle, deg
W3	Stage exit relative velocity, ft/sec
DIA	Rotor diameter, in.
S3	Stage exit entropy
ETT	Aerodynamic efficiency based on total-to-total pressure
V1	Volume flow into stage, ft^3/sec
H/D	Ratio of blade height to rotor diameter
M2	Mach number at nozzle exit
C/H	Ratio of blade chord to height
MR2	Relative Mach number at rotor inlet
H	Blade height, in.
V3	Vapor volume flow rate leaving stage, ft^3/sec
ETS	Aerodynamic efficiency based on total-to-static pressures
Q1	Vapor quality at stage inlet
Q3	Vapor quality at stage exit

Table 13. (continued)

```
NUMBER OF STAGES= 2                    RPM= 18000
INITIAL WEIGHT FLOW= 7.968

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4909     V1= .52288     Q1= 1
NS= 29.4283     DS= 2.22438    CO= 1275.61    H/D= 4.12115 E-2
C1= 330         C2= 1130.58    C3= 258.904    M2= 1.32509
A1= 90.         A2= 15         A3= 90         C/H= 1.3048
B2= 26.3349     W2= 688.781    W3= 583.62     MR2= .773095
UM= 583.054     UTIP= 545.033  DIA.= 6.93957  H= .28599
T3= 2162        HT3= 2.32286   S3= 2.52468    V3= 1.34861    Q3= .924129
STAGE EFF.= .698893            ETT= .762658   ETS= .73124

STAGE NO.-- 2
T1= 2162        HT1= 2.32286   S1= 2.52468    V1= 1.34861    Q1= .924129
NS= 53.6445     DS= 1.29151    CO= 1297.64    H/D= 8.49018 E-2
C1= 258.904     C2= 1206.06    C3= 397.33     M2= 1.52761
A1= 90.         A2= 21         A3= 90         C/H= .568957
B2= 36.3809     W2= 728.671    W3= 669.864    MR2= .922946
UM= 539.306     UTIP= 586.822  DIA.= 7.47164  H= .634356
T3= 1790        HT3= 2.16557   S3= 2.56927    V3= 4.71749    Q3= .846779
STAGE EFF.= .663439            ETT= .795286   ETS= .720724

TURBINE TOTAL ENTHALPY DROP= .326716      OVERALL CYCLE EFFICIENCY = .77897
OVERALL TURBINE EFFICIENCY= .699376

NEW WEIGHT FLOW= 7.96808

NUMBER OF STAGES= 3                    RPM= 18000
INITIAL WEIGHT FLOW= 7.679

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4909     V1= .52288     Q1= 1
NS= 32.2116     DS= 2.05891    CO= 1055.84    H/D= 4.77364 E-2
C1= 300         C2= 977.197    C3= 217.419    M2= 1.05743
A1= 90.         A2= 15.0313    A3= 90
B2= 26.515      W2= 567.682    W3= 487.011    MR2= .614289
UM= 435.79      UTIP= 457.062  DIA.= 5.8195   H= .277802
T3= 2298        HT3= 2.37199   S3= 2.51051    V3= .950736    Q3= .948578
STAGE EFF.= .725169            ETT= .768886   ETS= .736283

STAGE NO.-- 2
T1= 2298        HT1= 2.37199   S1= 2.51051    V1= .950736    Q1= .948578
NS= 46.3828     DS= 1.47269    CO= 1053.94    H/D= 7.01605 E-2
C1= 217.419     C2= 978.549    C3= 295.575    M2= 1.14696
A1= 90.         A2= 19.5       A3= 90
B2= 34.0018     W2= 584.111    W3= 528.549    MR2= .684639
UM= 438.182     UTIP= 469.909  DIA.= 5.98306  H= .419775
T3= 2032        HT3= 2.26128   S3= 2.53429    V3= 1.96066    Q3= .892134
STAGE EFF.= .696198            ETT= .789077   ETS= .727015

STAGE NO.-- 3
T1= 2032        HT1= 2.26128   S1= 2.53429    V1= 1.96066    Q1= .892134
NS= 68.676      DS= 1.04424    CO= 1084.81    H/D= .122278
C1= 295.575     C2= 1009.52    C3= 367.811    M2= 1.28315
A1= 90.         A2= 22.875     A3= 90
B2= 39.2606     W2= 620.080    W3= 581.197    MR2= .788162
UM= 450.009     UTIP= 507.797  DIA.= 6.46546  H= .790584
T3= 1790        HT3=2.15328   S3= 2.56436    V3= 4.68721    QQ3= .841331
STAGE EFF.= .667387            ETT= .803475   ETS= .711109

TURBINE TOTAL ENTHALPY DROP= .339008      OVERALL CYCLE EFFICIENCY = .78715
OVERALL TURBINE EFFICIENCY= .720276

NEW WEIGHT FLOW= 7.67918
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Table 13. (continued)

```
NUMBER OF STAGES= 4               RPM= 18000
INITIAL WEIGHT FLOW= 7.517

STAGE NO.-- 1
T1= 2610       HT1= 2.49228   S1= 2.4909    V1= .52288     Q1= 1
NS= 35.7899    DS= 1.87002    CO= 926.604   H/D= 5.29871 E-2
C1= 300        C2= 858.35     C3= 209.534   M2= .913289
A1= 90.        A2= 16.25      A3= 90        C/H= .993964
B2= 28.6232    W2= 501.392    W3= 437.395   MR2= .533484
UM= 383.942    UTIP= 404.792  DIA.= 5.15396 H= .273094
T3= 2367       HT3= 2.39828   S3= 2.50471   V3= .810415    Q3= .961751
STAGE EFF.= .742617           ETT= .775357  ETS= .735709

STAGE NO.-- 2
T1= 2367       HT1= 2.39828   S1= 2.50471   V1= .810415    Q1= .961751
NS= 47.1809    DS= 1.4506     CO= 911.133   H/D= 7.18677 E-2
C1= 209.534    C2= 846.033    C3= 257.586   M2= .953414
A1= 90.        A2= 19.625     A3= 90        C/H= .690433
B2= 34.2085    W2= 505.42     W3= 458.168   MR2= .569569
UM= 378.907    UTIP= 407.028  DIA.= 5.18244 H= .37245
T3= 2162       HT3= 2.31297   S3= 2.52015   V3= 1.339      Q3= .917483
STAGE EFF.= .718776           ETT= .789859  ETS= .72673

STAGE NO.-- 3
T1= 2162       HT1= 2.31297   S1= 2.52015   V1= 1.339      Q1= .917483
NS= 60.8954    DS= 1.15165    CO= 932.187   H/D= .100346
C1= 257.586    C2= 867.275    C3= 308.933   M2= 1.039
A1= 90.        A2= 22.5       A3= 90        C/H= .466958
B2= 38.6519    W2= 531.376    W3= 494.619   MR2= .636593
UM= 386.277    UTIP= 426.716  DIA.= 5.43311 H= .54519
T3= 1970       HT3= 2.22958   S3= 2.53883   V3= 2.38881    Q3= .876197
STAGE EFF.= .693856           ETT= .799838  ETS= .711991

STAGE NO.-- 4
T1= 1970       HT1= 2.22958   S1= 2.53883   V1= 2.38881    Q1= .876197
NS= 81.562     DS= .909545    CO= 959.404   H/D= .16014
C1= 308.933    C2= 893.409    C3= 342.156   M2= 1.1376
A1= 90.        A2= 23.875     A3= 90        C/H= .283868
B2= 40.7427    W2= 554.038    W3= 524.245   MR2= .705468
UM= 397.153    UTIP= 464.562  DIA.= 5.91498 H= .947227
T3= 1790       HT3= 2.14598   S3= 2.56187   V3= 4.67181    Q3= .83856
STAGE EFF.= .669683           ETT= .807666  ETS= .704941

TURBINE TOTAL ENTHALPY DROP= .346304      OVERALL CYCLE EFFICIENCY = .79318
OVERALL TURBINE EFFICIENCY= .731381

NEW WEIGHT FLOW= 7.51738

NUMBER OF STAGES= 5               RPM= 18000
INITIAL WEIGHT FLOW= 7.4075

STAGE NO.-- 1
T1= 2610       HT1= 2.49228   S1= 2.4909    V1= .52288     Q1= 1
NS= 39.2927    DS= 1.71519    CO= 839.569   H/D= 5.80322 E-2
C1= 300        C2= 778.422    C3= 207.16    M2= .82038
A1= 90.        A2= 17.5       A3= 90        C/H= .88878
B2= 30.7247    W2= 458.15     W3= 405.466   MR2= .482845
UM= 348.554    UTIP= 369.328  DIA.= 4.70242 H= .272892
T3= 2410       HT3= 2.41463   S3= 2.50138   V3= .737346    Q3= .970127
STAGE EFF.= .75502            ETT= .780678  ETS= .733147

STAGE NO.-- 2
T1= 2410       HT1= 2.41463   S1= 2.50138   V1= .737346    Q1= .970127
NS= 49.3637    DS= 1.3885     CO= 821.001   H/D= 7.49398 E-2
C1= 207.16     C2= 762.8      C3= 243.751   M2= .840402
A1= 90.        A2= 20.5       A3= 90        C/H= .651278
B2= 35.5662    W2= 459.281    W3= 419.071   MR2= .506006
UM= 340.894    UTIP= 367.307  DIA.= 4.67669 H= .35047
T3= 2241       HT3= 2.3445    S3= 2.5127    V3= 1.08824    Q3= .932983
STAGE EFF.= .734292           ETT= .791867  ETS= .722067

STAGE NO.-- 3
T1= 2241       HT1= 2.3445    S1= 2.5127    V1= 1.08824    Q1= .932983
NS= 59.9206    DS= 1.17256    CO= 832.439   H/D= 9.96843 E-2
C1= 243.751    C2= 774.148    C3= 267.693   M2= .895068
A1= 90.        A2= 21.875     A3= 90        C/H= .475955
B2= 37.7438    W2= 471.196    W3= 437.311   MR2= .544795
UM= 345.808    UTIP= 381.764  DIA.= 4.86077 H= .484542
T3= 2083       HT3= 2.27573   S3= 2.52603   V3= 1.67142    Q3= .898804
STAGE EFF.= .71229            ETT= .799301  ETS= .716644

STAGE NO.-- 4
T1= 2083       HT1= 2.27573   S1= 2.52603   V1= 1.67142    Q1= .898804
NS= 74.2624    DS= .979363    CO= 847.138   H/D= .137987
C1= 267.693    C2= 788.607    C3= 294.642   M2= .957377
A1= 90.        A2= 23.375     A3= 90        C/H= .33307
B2= 40.0051    W2= 486.699    W3= 458.331   MR2= .590858
UM= 351.079    UTIP= 402.158  DIA.= 5.12043 H= .706552
T3= 1933       HT3= 2.20797   S3= 2.54168   V3= 2.70569    Q3= .866581
STAGE EFF.= .691279           ETT= .805518  ETS= .708075

STAGE NO.-- 5
T1= 1933       HT1= 2.20797   S1= 2.54168   V1= 2.70569    Q1= .866581
NS= 94.4302    DS= .811549    CO= 865.176   H/D= .200787
C1= 294.642    C2= 806.255    C3= 324.83    M2= 1.028
A1= 90.        A2= 25         A3= 90        C/H= .220918
B2= 42.3286    W2= 506.009    W3= 482.384   MR2= .645176
UM= 356.626    UTIP= 432.773  DIA.= 5.51023 H= 1.10638
T3= 1790       HT3= 2.14084   S3= 2.56      V3= 4.66029    Q3= .836489
STAGE EFF.= .671764           ETT= .810455  ETS= .696212

TURBINE TOTAL ENTHALPY DROP= .35144       OVERALL CYCLE EFFICIENCY = .79756
OVERALL TURBINE EFFICIENCY= .739422

NEW WEIGHT FLOW= 7.40753
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Table 13. (continued)

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NUMBER OF STAGES= 2               RPM= 18000
INITIAL WEIGHT FLOW= 6.868

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4709      V1= .52288      Q1= 1
NS= 26.7069     DS= 2.41634    CO= 1385.94     H/D= 3.52482, E-2
C1= 300         C2= 1282.68    C3= 277.027     M2= 1.46924
A1= 90.         A2= 15         A3= 90          C/H= 1.5279
B2= 26.1762     W2= 752.567    W3= 627.993     MR2= .862024
UM= 563.59      UTIP= 583.789  DIA.= 7.43303   H= .261956
T3= 2091        HT3= 2.29693   S3= 2.53332     V3= 1.65271     Q3= .911717
STAGE EFF.= .681854            ETT= .754781    ETS= .724816

STAGE NO.-- 2
T1= 2091        HT1= 2.29693   S1= 2.53332     V1= 1.65271     Q1= .911717
NS= 57.8516     DS= 1.20509    CO= 1428.69     H/D= 9.33441 E-2
C1= 277.027     C2= 1328.76    C3= 461.266     M2= 1.76159
A1= 90.         A2= 22         A3= 90          C/H= .507222
B2= 37.8982     W2= 810.344    W3= 750.928     MR2= 1.07431
UM= 592.563     UTIP= 650.134  DIA.= 8.27776   H= .77268
T3= 1660        HT3= 2.11324   S3= 2.59381     V3= 8.49507     Q3= .823321
STAGE EFF.= .6466              ETT= .798091    ETS= .7149

TURBINE TOTAL ENTHALPY DROP= .379044       OVERALL CYCLE EFFICIENCY = .77654
OVERALL TURBINE EFFICIENCY= .689329

NEW WEIGHT FLOW= 6.86806

NUMBER OF STAGES= 3               RPM= 18000
INITIAL WEIGHT FLOW= 6.593

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4709      V1= .52288      Q1= 1
NS= 28.0738     DS= 2.31568    CO= 1144.79     H/D= 3.81776 E-2
C1= 300         C2= 1059.5     C3= 230.699     M2= 1.16138
A1= 90.         A2= 15         A3= 90          C/H= 1.4094
B2= 26.2605     W2= 619.769    W3= 521.408     MR2= .679328
UM= 467.597     UTIP= 485.775  DIA.= 6.18508   H= .236131
T3= 2249        HT3= 2.35387   S3= 2.51517     V3= 1.07213     Q3= .939435
STAGE EFF.= .708505            ETT= .759063    ETS= .728237

STAGE NO.-- 2
T1= 2249        HT1= 2.35387   S1= 2.51517     V1= 1.07213     Q1= .939435
NS= 43.8705     DS= 1.54952    CO= 1151.28     H/D= 6.55505 E-2
C1= 230.699     C2= 1068.46    C3= 310.619     M2= 1.28815
A1= 90.         A2= 18.875     A3= 90          C/H= .767753
B2= 32.9888     W2= 634.834    W3= 570.494     MR2= .765362
UM= 478.522     UTIP= 510.834  DIA.= 6.50414   H= .42635
T3= 1940        HT3= 2.22418   S3= 2.54675     V3= 2.66286     Q3= .875409
STAGE EFF.= .679185            ETT= .786413    ETS= .729166

STAGE NO.-- 3
T1= 1940        HT1= 2.22418   S1= 2.54675     V1= 2.66286     Q1= .875409
NS= 73.7789     DS= .984192    CO= 1195.62     H/D= .136421
C1= 310.619     C2= 1113.01    C3= 415.743     M2= 1.48114
A1= 90.         A2= 23.375     A3= 90          C/H= .336908
B2= 40.0[illegible]7    W2= 686.954    W3= 646.757     MR2= .91417
UM= 495.[illegible]36   UTIP= 566.674  DIA.= 7.21512   H= .984297
T3= 1660        HT3= 2.09743   S3= 2.58802     V3= 8.43538     Q3= .817529
STAGE EFF.= .649152            ETT= .805358    ETS= .707981

TURBINE TOTAL ENTHALPY DROP= .394852       OVERALL CYCLE EFFICIENCY = .78361
OVERALL TURBINE EFFICIENCY= .710066

NEW WEIGHT FLOW= 6.59311
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Table 13. (continued)

```
NUMBER OF STAGES= 4                       RPM= 18000
INITIAL WEIGHT FLOW= 6.448

STAGE NO.-- 1
T1= 2610          HT1= 2.49228    S1= 2.4909       V1= .52288      Q1= 1
NS= 30.7913       DS= 2.14002     CO= 1002.7       H/D= 4.43884 E-2
C1= 300           C2= 927.998     C3= 204.817      M2= .996443
A1= 90.           A2= 15          A3= 90           C/H= 1.21072
B2= 26.4018       W2= 540.146     W3= 460.609      MR2= .579985
UM= 412.57        UTIP= 431.269   [illegible] 5.49108  H= .24374
T3= 2328          HT3= 2.38336    [illegible]50816 V3= .886129     Q3= .954611
STAGE EFF.= .727507               [illegible]45885 ETS= .73393

STAGE NO.-- 2
T1= 2328          HT1= 2.38336    S1= 2.50816      V1= .886129     Q1= .954611
NS= 42.9679       DS= 1.57571     CO= 985.727      H/D= 6.28922 E-2
C1= 204.817       C2= 914.9       C3= 267.299      M2= 1.05271
A1= 90.           A2= 19          A3= 90           C/H= .79867
B2= 33.1576       W2= 544.593     W3= 488.713      MR2= .626623
UM= 409.139       UTIP= 435.618   DIA.= 5.54645    H= .348829
T3= 2091          HT3= 2.285      S3= 2.52801      V3= 1.63939     Q3= .904311
STAGE EFF.= .733219               ETT= .785372     ETS= .727621

STAGE NO.-- 3
T1= 2091          HT1= 2.285      S1= 2.52801      V1= 1.63939     Q1= .904311
NS= 59.0645       DS= 1.17559     CO= 1019.56      H/D= 9.35865 E-2
C1= 267.299       C2= 948.878     C3= 345.096      M2= 1.17419
A1= 90.           A2= 23          A3= 90           C/H= .49586
B2= 39.337        W2= 584.898     W3= 544.416      MR2= .723782
UM= 421.07        UTIP= 462.089   DIA.= 5.88349    H= .550616
T3= 1869          HT3= 2.18819    S3= 2.55273      V3= 3.42779     Q3= .856928
STAGE EFF.= .676963               ETT= .798725     ETS= .707219

STAGE NO.-- 4
T1= 1869          HT1= 2.18819    S1= 2.55273      V1= 3.42779     Q1= .856928
NS= 86.6425       DS= .869005     CO= 1064.88      H/D= .176737
C1= 345.096       C2= 991.797     C3= 384.567      M2= 1.32247
A1= 90.           A2= 24.125      A3= 90           C/H= .255782
B2= 41.1113       W2= 616.518     W3= 584.871      MR2= .822072
UM= 440.664       UTIP= 523.341   DIA.= 6.66339    H= 1.17766
T3= 1660          HT3= 2.08853    S3= 2.58499      V3= 8.40413     Q3= .814496
STAGE EFF.= .650468               ETT= .808893     ETS= .703398

TURBINE TOTAL ENTHALPY DROP= .403758       OVERALL CYCLE EFFICIENCY = .78972
OVERALL TURBINE EFFICIENCY= .721055

NEW WEIGHT FLOW= 6.44767

NUMBER OF STAGES= 5                       RPM= 18000
INITIAL WEIGHT FLOW= 6.34

STAGE NO.-- 1
T1= 2610          HT1= 2.49228    S1= 2.4909       V1= .52288      Q1= 1
NS= 33.5418       DS= 1.98684     CO= 906.824      H/D= 5.03885 E-2
C1= 300           C2= 839.417     C3= 190.503      M2= .890739
A1= 90.           A2= 15.25       A3= 90           C/H= 1.06168
B2= 26.9242       W2= 487.603     W3= 420.71       MR2= .517415
UM= 375.109       UTIP= 394.458   DIA.= 5.0224     H= .253071
T3= 2378          HT3= 2.40179    S3= 2.50404      V3= .791045     Q3= .964212
STAGE EFF.= .740886               ETT= .771429     ETS= .737384

STAGE NO.-- 2
T1= 2378          HT1= 2.40179    S1= 2.50404      V1= .791045     Q1= .964212
NS= 44.218        DS= 1.53926     CO= 882.203      H/D= 6.64457 E-2
C1= 190.503       C2= 818.744     C3= 238.186      M2= .916719
A1= 90.           A2= 18.875      A3= 90           C/H= .757337
B2= 32.9972       W2= 486.353     W3= 437.359      MR2= .544552
UM= 366.815       UTIP= 391.932   DIA.= 4.99023    H= .331579
T3= 2183          HT3= 2.32109    S3= 2.51843      V3= 1.2658      Q3= .922163
STAGE EFF.= .719765               ETT= .786797     ETS= .729444

STAGE NO.-- 3
T1= 2183          HT1= 2.32109    S1= 2.51843      V1= 1.2658      Q1= .922163
NS= 55.7369       DS= 1.24935     CO= 905.115      H/D= .089893
C1= 238.186       C2= 841.38      C3= 281.251      M2= .99821
A1= 90.           A2= 21.25       A3= 90           C/H= .534599
B2= 36.7795       W2= 509.318     W3= 469.739      MR2= .604252
UM= 376.238       UTIP= 411.398   DIA.= 5.23807    H= .470866
T3= 1999          HT3= 2.24107    S3= 2.53593      V3= 2.17198     Q3= .882688
STAGE EFF.= .69576                ETT= .796739     ETS= .719809

STAGE NO.-- 4
T1= 1999          HT1= 2.24107    S1= 2.53593      V1= 2.17198     Q1= .882688
NS= 73.3135       DS= .990041     CO= 927.136      H/D= .135443
C1= 281.251       C2= 863.006     C3= 320.528      M2= 1.08497
A1= 90.           A2= 23.25       A3= 90           C/H= .340225
B2= 39.8237       W2= 531.934     W3= 500.488      MR2= .668746
UM= 384.387       UTIP= 439.248   DIA.= 5.59268    H= .757489
T3= 1826          HT3= 2.16187    S3= 2.55696      V3= 4.03885     Q3= .8462
STAGE EFF.= .673413               ETT= .805197     ETS= .708959

STAGE NO.-- 5
T1= 1826          HT1= 2.16187    S1= 2.55696      V1= 4.03885     Q1= .8462
NS= 100.41        DS= .781391     CO= 958.884      H/D= .225481
C1= 320.528       C2= 893.436     C3= 356.835      M2= 1.19305
A1= 90.           A2= 24.75       A3= 90           C/H= .19771
B2= 42.0125       W2= 558.866     W3= 533.15       MR2= .746283
UM= 396.132       UTIP= 491.069   DIA.= 6.25248    H= 1.40981
T3= 1660          HT3= 2.08167    S3= 2.58278      V3= 8.38135     Q3= .812285
STAGE EFF.= .651615               ETT= .811456     ETS= .699082

TURBINE TOTAL ENTHALPY DROP= .410618       OVERALL CYCLE EFFICIENCY = .79432
OVERALL TURBINE EFFICIENCY= .729146

NEW WEIGHT FLOW= 6.33996
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Table 13. (continued)

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NUMBER OF STAGES= 1                    RPM= 18000
INITIAL WEIGHT FLOW= 8.166

STAGE NO.-- 1
T1= 2460        HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 43.9992     DS= 1.5457      CO= 1835.48     H/D= 6.98813 E-2
C1  300         C2= 1703.45     C3= 495.348     M2= 2.22193
A1= 90.         A2= 18.875      A3= 90          C/H= .76387
B2= 32.9919     W2= 1012.03     W3= 989.692     MR2= 1.31953
UM= 763.009     UTIP= 814.798   DIA.= 10.3743   H= .683474
T3= 1660        HT3= 2.16149    S3= 2.61982     V3= 8.76347     Q3= .849366
STAGE EFF.= .656884             ETT= [illegible]6556   ETS= .72927

TURBINE TOTAL ENTHALPY DROP= .31883        OVERALL CYCLE EFFICIENCY = .78656
OVERALL TURBINE EFFICIENCY= .656909

NEW WEIGHT FLOW= 8.16518

NUMBER OF STAGES= 2                    RPM= 18000
INITIAL WEIGHT FLOW= 7.5365

STAGE NO.-- 1
T1= 2460        HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 33.9781     DS= 1.96279     CO= 1315.1      H/D= 5.07047 E-2
C1= 300         C2= 1217.57     C3= 281.411     M2= 1.40629
A1= 90.         A2= 15.5        A3= 90          C/H= 1.05108
B2= 27.3468     W2= 703.31      W3= 612.594     MR2= .818096
UM= 544.134     UTIP= 578.382   DIA.= 7.28779   H= .369525
T3= 2023        HT3= 2.3        S3= 2.55703     V3= 2.0821      Q3= .919166
STAGE EFF.= .703198             ETT= .772216    ETS= .736857

STAGE NO.-- 2
T1= 2023        HT1= 2.3        S1= 2.55703     V1= 2.0821      Q1= .919166
NS= 66.936      DS= 1.06641     CO= [illegible]    H/D= .117393
C1= 281.411     C2= 1251.08     C3= 452.771     M2= 1.64393
A1= 90.         A2= 22.75       A3= 90          C/H= .396815
B2= 39.0687     W2= 767.637     W3= 718.397     MR2= 1.00868
UM= 557.759     UTIP= 626.428   DIA.= 7.97593   H= .936321
T3= 1660        HT3= 2.1349     S3= 2.60758     V3= 8.63719     Q3= .837112
STAGE EFF.= .663035             ETT= .802753    ETS= .711715

TURBINE TOTAL ENTHALPY DROP= .345421       OVERALL CYCLE EFFICIENCY = .83711
OVERALL TURBINE EFFICIENCY= .702617

NEW WEIGHT FLOW= 7.53659

NUMBER OF STAGES= 3                    RPM= 18000
INITIAL WEIGHT FLOW= 7.25

STAGE NO.-- 1
T1= 2460        HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 36.3855     DS= 1.84268     CO= 1087.65     H/D= [illegible].41019 E-2
C1= 300         C2= 1007.63     C3= 248.379     M2= 1.11774
A1= 90.         A2= 16.375      A3= 90
B2= 28.8443     W2= 588.836     W3= 514.848     MR2= .653185
UM= 450.975     UTIP= 475.991   DIA.= 6.0605    H= .327885
T3= 2156        HT3= 2.35317    S3= 2.54087     V3= 1.49456     Q3= .945765
STAGE EFF.= .729845             ETT= .776323    ETS= .735839

STAGE NO.-- 2
T1= 2156        HT1= 2.35317    S1= 2.54087     V1= 1.40456     Q1= .945765
NS= 54.1911     DS= 1.27603     CO= 1095.21     H/D= 8.48045 E-2
C1= 248.379     C2= 1018.26     C3= 343.89      M2= 1.2314
A1= 90.         A2= 21.5        A3= 90
B2= 37.1217     W2= 618.373     W3= 569.815     MR2= .747808
UM= 454.348     UTIP= 494.332   DIA.= 6.29403   H= .533762
T3= 1896        HT3= 2.2361     S3= 2.56773     V3= 3.18099     Q3= .884821
STAGE EFF.= .696878             ETT= .795675    ETS= .717228

STAGE NO.-- 3
T1= 1896        HT1= 2.2361     S1= 2.56773     V1= 3.18099     Q1= .884821
NS= 84.6911     DS= .879801     CO= 1132.25     H/D= .16805
C1= 343.89      C2= 1054.8      C3= 415.161     M2= 1.39057
A1= 90.         A2= 24.5        A3= 90
B2= 41.6136     W2= 658.656     W3= 625.145     MR2= .868326
UM= 467.386     UTIP= 550.673   DIA.= 7.01139   H= 1.17826
T3= 1660        HT3= 2.12134    S3= 2.60247     V3= 8.58444     Q3= .831993
STAGE EFF.= .665581             ETT= .808445    ETS= .699752

TURBINE TOTAL ENTHALPY DROP= .358982       OVERALL CYCLE EFFICIENCY = .79348
OVERALL TURBINE EFFICIENCY= .722745

NEW WEIGHT FLOW= 7.25189
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Table 13. (continued)

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NUMBER OF STAGES= 4                RPM= 18000
INITIAL WEIGHT FLOW= 7.0729

STAGE NO.-- 1
T1= 2460          HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 40.0518       DS= 1.6851      CO= 953.805     H/D= .0592
C1= 300           C2= 684.495     C3= 239.314     M2= .961784
A1= 90.           A2= 17.75       A3= 90          C/H= .867472
B2= 31.14         W2= 521.435     W3= 462.771     MR2= .567
UM= 396.09        UTIP= 420.183   DIA.= 5.34993   H= .316716
T3= 2223          HT3= 2.38131    S3= 2.53437     V3= 1.17645     Q3= .960165
STAGE EFF.= .747486               ETT= .781717    ETS= .732505

STAGE NO.-- 2
T1= 2223          HT1= 2.38131    S1= 2.53437     V1= 1.17645     Q1= .960165
NS= 53.6262       DS= 1.29187     CO= 947.376     H/D= 8.48514 E-2
C1= 239.314       C2= 880.516     C3= 290.076     M2= 1.02116
A1= 90.           A2= 21          A3= 90          C/H= .56929
B2= 36.3806       W2= 531.99      W3= 489.046     MR2= .616977
UM= 393.731       UTIP= 428.399   DIA.= 5.45455   H= .462826
T3= 2023          HT3= 2.29034    S3= 2.55187     V3= 2.06668     Q3= .912322
STAGE EFF.= .719828               ETT= .795273    ETS= .720715

STAGE NO.-- 3
T1= 2023          HT1= 2.29034    S1= 2.55187     V1= 2.06668     Q1= .912322
NS= 71.7384       DS= 1.00763     CO= 970.573     H/D= .130913
C1= 290.076       C2= 903.363     C3= 333.398     M2= 1.1172
A1= 90.           A2= 23.125      A3= 90          C/H= .352952
B2= 39.637        W2= 556.158     W3= 522.631     MR2= .687809
UM= 402.401       UTIP= 457.941   DIA.= 5.83068   H= .763312
T3= 1836          HT3= 2.20097    S3= 2.57351     V3= 3.97686     Q3= .868877
STAGE EFF.= .692249               ETT= .804643    ETS= .709698

STAGE NO.-- 4
T1= 1836          HT1= 2.20097    S1= 2.57351     V1= 3.97686     Q1= .868877
NS= 101.085       DS= .778018     CO= 997.103     H/D= .228211
C1= 333.398       C2= 929.047     C3= 371.112     M2= 1.22655
A1= 90.           A2= 24.75       A3= 90          C/H= .195339
B2= 42.0146       W2= 581.118     W3= 554.461     MR2= .767206
UM= 411.952       UTIP= 511.855   DIA.= 6.51714   H= 1.48728
T3= 1660          HT3= 2.11226    S3= 2.60024     V3= 8.56145     Q3= .829762
STAGE EFF.= .66658                ETT= .811559    ETS= .699137

TURBINE TOTAL ENTHALPY DROP= .368063      OVERALL CYCLE EFFICIENCY = .79830
OVERALL TURBINE EFFICIENCY= .733084

NEW WEIGHT FLOW= 7.07298

NUMBER OF STAGES= 5                RPM= 18000
INITIAL WEIGHT FLOW= 6.9345

STAGE NO.-- 1
T1= 2460          HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 43.6768       DS= 1.55654     CO= 863.594     H/D= 6.54299 E-2
C1= 300           C2= 801.403     C3= 231.301     M2= .861016
A1= 90.           A2= 18.75       A3= 90          C/H= .770881
B2= 32.7917       W2= 475.644     W3= 427.08      MR2= .511025
UM= 359.026       UTIP= 383.223   DIA.= 4.87935   H= .319255
T3= 2265          HT3= 2.39861    S3= 2.53054     V3= 1.05917     Q3= .969226
STAGE EFF.= .759697               ETT= .786192    ETS= .729794

STAGE NO.-- 2
T1= 2265          HT1= 2.39861    S1= 2.53054     V1= 1.05917     Q1= .969226
NS= 55.1586       DS= 1.26003     CO= 854.593     H/D= 8.82747 E-2
C1= 231.301       C2= 794.416     C3= 265.384     M2= .89898
A1= 90.           A2= 21.25       A3= 90          C/H= .544458
B2= 36.7712       W2= 480.982     W3= 443.324     MR2= .544291
UM= 355.12        UTIP= 387.69    DIA.= 4.93622   H= .435743
T3= 2100          HT3= 2.3232     S3= 2.54346     V3= 1.63696     Q3= .929123
STAGE EFF.= .73538                ETT= .796353    ETS= .719558

STAGE NO.-- 3
T1= 2100          HT1= 2.3232     S1= 2.54346     V1= 1.63696     Q1= .929123
NS= 69.0042       DS= 1.04041     CO= 864.823     H/D= .1233
C1= 265.384       C2= 804.803     C3= 293.283     M2= .958977
A1= 90.           A2= 22.875      A3= 90          C/H= .376761
B2= 39.2633       W2= 494.314     W3= 463.404     MR2= .589008
UM= 358.79        UTIP= 405.262   DIA.= 5.15996   H= .636223
T3= 1946          HT3= 2.25003    S3= 2.55871     V3= 2.65501     Q3= .892496
STAGE EFF.= .711384               ETT= .803605    ETS= .711187

STAGE NO.-- 4
T1= 1946          HT1= 2.25003    S1= 2.55871     V1= 2.65501     Q1= .892496
NS= 84.1425       DS= .883898     CO= 934.066     H/D= .166148
C1= 293.283       C2= 870.171     C3= 342.428     M2= 1.09934
A1= 90.           A2= 24.5        A3= 90          C/H= .270002
B2= 41.6109       W2= 543.398     W3= 515.65      MR2= .68651
UM= 385.539       UTIP= 453.445   DIA.= 5.77344   H= .959244
T3= 1780          HT3= 2.1697     S3= 2.57951     V3= 4.9739      Q3= .854292
STAGE EFF.= .684432               ETT= .808313    ETS= .699679

STAGE NO.-- 5
T1= 1780          HT1= 2.1697     S1= 2.57951     V1= 4.9739      Q1= .854292
NS= 126.221       DS= .678614     CO= 853.775     H/D= .348309
C1= 342.428       C2= 795.695     C3= 324.094     M2= 1.05143
A1= 90.           A2= 25.125      A3= 90          C/H= .126845
B2= 42.5781       W2= 499.335     W3= 479.007     MR2= .65932
UM= 352.722       UTIP= 477.34    DIA.= 6.07767   H= 2.11691
T3= 1660          HT3= 2.1049     S3= 2.59887     V3= 8.54726     Q3= .828385
STAGE EFF.= .668427               ETT= .814566    ETS= .69719

TURBINE TOTAL ENTHALPY DROP= .375425      OVERALL CYCLE EFFICIENCY = .80181
OVERALL TURBINE EFFICIENCY= .740259

NEW WEIGHT FLOW= 6.93428
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Table 13. (continued)

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NUMBER OF STAGES= 1                    RPM= 24000
INITIAL WEIGHT FLOW= 8.698

STAGE NO.-- 1
T1= 2610        HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 46.749      DS= 1.45814     CO= 17[illegible]4.87    H/D= 6.96171 E-2
C1= 300         C2= 1652.2      C3= 5[illegible].563     M2= 2.08352
A1= 90.         A2= 20          A3= 9[illegible]         C/H= .708013
B2= 34.765      W2= 991.008     W3= 818.897     MR2= 1.24972
UM= 738.448     UTIP= 791.491   DIA.= 7.55818   H= .526179
T3= 1790        HT3= 2.193      S3= 2.57549     V3= 4.75588     Q3= .853687
STAGE EFF.= .663788             ETT= .789434    ETS= .723892

TURBINE TOTAL ENTHALPY DROP= .299288      OVERALL CYCLE EFFICIENCY = .78943
OVERALL TURBINE EFFICIENCY= .663813

NEW WEIGHT FLOW= 8.6983

NUMBER OF STAGES= 2                    RPM= 24000
INITIAL WEIGHT FLOW= 7.9962

STAGE NO.-- 1
T1= 2610        HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 39.2396     DS= 1.71841     CO= 1275.61     H/D= .058272
C1= 300         C2= 1182.6      C3= 312.363     M2= 1.32993
A1= 90.         A2= 17.375      A3= 90
B2= 30.5262     W2= 695.278     W3= 614.967     MR2= .781892
UM= 529.733     UTIP= 561.438   DIA.= 5.36134   H= .312416
T3= 2162        HT3= 2.3229     S3= 2.5225      V3= 1.34399     Q3= .920931
STAGE EFF.= .712655             ETT= .7806      ETS= .733793

STAGE NO.-- 2
T1= 2162        HT1= 2.3229     S1= 2.5225      V1= 1.34399     Q1= .920931
NS= 70.6807     DS= 1.0157      CO= 1307.36     H/D= .12609
C1= 312.363     C2= 1217.13     C3= 456.348     M2= 1.54575
A1= 90.         A2= 23.5        A3= 90
B2= 40.1531     W2= 752.644     W3= 707.701     MR2= .955857
UM= 540.918     UTIP= 612.619   DIA.= 5.85008   H= .737635
T3= 1790        HT3= 2.16668    S3= 2.56552     V3= 4.69434     Q3= .842615
STAGE EFF.= .669884             ETT= .804257    ETS= .706263

TURBINE TOTAL ENTHALPY DROP= .325601      OVERALL CYCLE EFFICIENCY = .79243
OVERALL TURBINE EFFICIENCY= .708868

NEW WEIGHT FLOW= 7.99537

NUMBER OF STAGES= 3                    RPM= 24000
INITIAL WEIGHT FLOW= 7.6645

STAGE NO.-- 1
T1= 2610        HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 42.8505     DS= 1.57935     CO= 1055.84     H/D= .062598
C1= 300         C2= 979.974     C3= 286.241     M2= 1.06205
A1= 90.         A2= 19          A3= 90          C/H= .802452
B2= 33.1545     W2= 583.376     W3= 523.386     MR2= .632238
UM= 438.182     UTIP= 466.404   DIA.= 4.45383   H= .278801
T3= 2298        HT3= 2.3737     S3= 2.50891     V3= .948182     Q3= .945994
STAGE EFF.= .738877             ETT= .785232    ETS= .72752

STAGE NO.-- 2
T1= 2298        HT1= 2.3737     S1= 2.50891     V1= .948182     Q1= .945994
NS= 60.3786     DS= 1.15956     CO= 1068.98     H/D= 9.88634 E-2
C1= 286.241     C2= 994.539     C3= 354.107     M2= 1.16801
A1= 90.         A2= 22.5        A3= 90          C/H= .474
B2= 38.6459     W2= 609.431     W3= 567.019     MR2= .715729
UM= 442.856     UTIP= 488.51    DIA.= 4.66493   H= .461191
T3= 2032        HT3= 2.26234    S3= 2.5319      V3= 1.9537      Q3= .888944
STAGE EFF.= .704521             ETT= .799552    ETS= .711816

STAGE NO.-- 3
T1= 2032        HT1= 2.26234    S1= 2.5319      V1= 1.9537      Q1= .888944
NS= 89.3836     DS= .849245     CO= 1100.51     H/D= .186012
C1= 354.107     C2= 1025.06     C3= 399.897     M2= 1.30523
A1= 90.         A2= 24.25       A3= 90          C/H= .242349
B2= 41.2942     W2= 637.967     W3= 605.971     MR2= .812338
UM= 455.287     UTIP= 545.273   DIA.= 5.20697   H= .968559
T3= 1790        HT3= 2.15263    S3= 2.56186     V3= 4.67[illegible]9     Q3= .838557
STAGE EFF.= .671669             ETT= .809482    ETS= .70[illegible]

TURBINE TOTAL ENTHALPY DROP= .339652      OVERALL CYCLE EFFICIENCY = 79809
OVERALL TURBINE EFFICIENCY= .727562

NEW WEIGHT FLOW= 7.6646
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Table 13. (continued)

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NUMBER OF STAGES= 4                    RPM= 24000
INITIAL WEIGHT FLOW= 7.488

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4909     V1= .52288     Q1= 1
NS= 47.5817     DS= 1.4916    CO= 926.604    H/D= 7.25362 E-2
C1= 300         C2= 860.473    C3= 263.876    M2= .916564
A1= 90.         A2= 19.75      A3= 90         C/H= .682462
B2= 34.406      W2= 514.584    W3= 466.992    MR2= .548128
UM= 385.297     UTIP= 414.166  DIA.= 3.95499  H= .28688
T3= 2367        HT3= 2.39964   S3= 2.5036     V3= .808852    Q3= .959867
STAGE EFF.= .755678            ETT= .790243   ETS= .726156

STAGE NO.-- 2
T1= 2367        HT1= 2.39964   S1= 2.5036     V1= .808852    Q1= .959867
NS= 61.3643     DS= 1.1446     CO= 924.349    H/D= .101699
C1= 263.876     C2= 859.983    C3= 306.458    M2= .970558
A1= 90.         A2= 22.5       A3= 90         C/H= .460711
B2= 38.6573     W2= 526.847    W3= 490.599    MR2= .594588
UM= 383.109     UTIP= 423.774  DIA.= 4.04674  H= .411549
T3= 2162        HT3= 2.31369   S3= 2.5185     V3= 1.3355     Q3= .915065
STAGE EFF.= .727356            ETT= .800092   ETS= .712147

STAGE NO.-- 3
T1= 2162        HT1= 2.31369   S1= 2.5185     V1= 1.3355     Q1= .915065
NS= 79.1942     DS= .930398    CO= 945.783    H/D= .15266
C1= 306.458     C2= 880.653    C3= 335.158    M2= 1.05653
A1= 90.         A2= 23.75      A3= 90         C/H= .298608
B2= 40.557      W2= 545.189    W3= 515.465    MR2= .654427
UM= 391.632     UTIP= 454.866  DIA.= 4.34365  H= .663101
T3= 1970        HT3= 2.22871   S3= 2.53706    V3= 2.38269    Q3= .873939
STAGE EFF.= .699244            ETT= .807025   ETS= .70568

STAGE NO.-- 4
T1= 1970        HT1= 2.22871   S1= 2.53706    V1= 2.38269    Q1= .873939
NS= 107.104     DS= .749028    CO= 967.106    H/D= .252648
C1= 335.158     C2= 901.171    C3= 362.256    M2= 1.14912
A1= 90.         A2= 24.875     A3= 90         C/H= .17593
B2= 42.2        W2= 564.323    W3= 539.294    MR2= .719591
UM= 399.515     UTIP= 506.418  DIA.= 4.83594  H= 1.22179
T3= 1790        HT3= 2.14462   S3= 2.55988    V3= 4.65954    Q3= .836353
STAGE EFF.= .673074            ETT= .812412   ETS= .698424

TURBINE TOTAL ENTHALPY DROP= .347662      OVERALL CYCLE EFFICIENCY = .80244
OVERALL TURBINE EFFICIENCY= .737677

NEW WEIGHT FLOW= 7.48801

NUMBER OF STAGES= 5                    RPM= 24000
INITIAL WEIGHT FLOW= 7.363

STAGE NO.-- 1
T1= 2610        HT1= 2.49228   S1= 2.4909     V1= .52288     Q1= 1
NS= 52.1937     DS= 1.32342    CO= 839.569    H/D= 8.17382 E-2
C1= 3 0         C2= 780.185    C3= 253.426    M2= .822948
A1= 90.         A2= 20.75      A3= 90
B2= 35.9881     W2= 470.394    W3= 431.276    MR2= .496177
UM= 348.964     UTIP= 378.531  DIA.= 3.6147   H= .295459
T3= 2410        HT3= 2.4159    S3= 2.50053    V3= .736246    Q3= .968653
STAGE EFF.= .76722             ETT= .794198   ETS= .721835

STAGE NO.-- 2
TIX 2410        HT1= 2.4159    S1= 2.50053    V1= .736246    Q1= .968653
NS= 64.1106     DS= 1.10661    CO= 833.328    H/D= .110242
C1= 253.426     C2= 775.835    C3= 275.287    M2= .854993
A1= 90.         A2= 22.375     A3= 90
B2= 38.5083     W2= 473.968    W3= 442.136    MR2= .522731
UM= 345.981     UTIP= 385.898  DIA.= 3.68505  H= .406246
T3= 2241        HT3= 2.34453   S3= 2.51158    V3= 1.08624    Q3= .931245
STAGE EFF.= .742413            ETT= .801471   ETS= .714007

STAGE NO.-- 3
T1= 2241        HT1= 2.34453   S1= 2.51158    V1= 1.08624    Q1= .931245
NS= 78.2797     DS= .939497    CO= 841.537    H/D= .150149
C1= 275.287     C2= 783.522    C3= 296.481    M2= .907012
A1= 90.         A2= 23.625     A3= 90
B2= 40.3785     W2= 484.684    W3= 457.648    MR2= .561075
UM= 348.631     UTIP= 403.969  DIA.= 3.85762  H= .579216
T3= 2083        HT3= 2.27528   S3= 2.5246     V3= 1.66777    Q3= .896824
STAGE EFF.= .718474            ETT= .806762   ETS= .706625

STAGE NO.-- 4
T1= 2083        HT1= 2.27528   S1= 2.5246     V1= 1.66777    Q1= .896824
NS= 97.0944     DS= .796589    CO= 855.866    H/D= .21094
C1= 296.481     C2= 797.58     C3= 321.55     M2= .969566
A1= 90.         A2= 25         A3= 90
B2= 42.3379     W2= 500.475    W3= 477.428    MR2= .608395
UM= 352.909     UTIP= 432.08   DIA.= 4.12606  H= .870351
T3= 1933        HT3= 2.20725   S3= 2.53998    V3= 2.69912    Q3= .864468
STAGE EFF.= .695594            ETT= .810922   ETS= .69647

STAGE NO.-- 5
T1= 1933        HT1= 2.20725   S1= 2.53998    V1= 2.69912    Q1= .864468
NS= 123.549     DS= .686651    CO= 873.809    H/D= .33205
C1= 321.55      C2= 814.366    C3= 331.57     M2= 1.03947
A1= 90.         A2= 25.125     A3= 90
B2= 42.5727     W2= 511.104    W3= 490.107    MR2= .652382
UM= 360.927     UTIP= 483.861  DIA.= 4.62053  H= 1.53425
T3= 1790        HT3= 2.13883   S3= 2.55849    V3= 4.65096    Q3= .83481
STAGE EFF.= .673676            ETT= .814297   ETS= .69705

TURBINE TOTAL ENTHALPY DROP= .353458      OVERALL CYCLE EFFICIENCY = .80553
OVERALL TURBINE EFFICIENCY= .744747

NEW WEIGHT FLOW= 7.36523
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Table 13. (continued)

```
NUMBER OF STAGES= 2                 RPM= 24000
INITIAL WEIGHT FLOW= 6.874

STAGE NO.-- 1
T1= 2610         HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 35.5553      DS= 1.87797     CO= 1385.94     H/D= 5.16781 E-2
C1= 300          C2= 1284.08     C3= 318.187     M2= 1.47405
A1= 90.          A2= 16.5        A3= 90          C/H= 1.01531
B2= 29.015       W2= 751.895     W3= 656.002     MR2= .863131
UM= 573.675      UTIP= 604.041   DIA.= 5.76816   H= .298088
T3= 2091         HT3= 2.29537    S3= 2.53075     V3= 1.64627     Q3= .908137
STAGE EFF.= .696469              ETT= .774959    ETS= .734112

STAGE NO.-- 2
T1= 2091         HT1= 2.29537    S1= 2.53075     V1= 1.64627     Q1= .908137
NS= 76.468       DS= .952547     CO= 1434.76     H/D= .142551
C1= 318.187      C2= 1336.18     C3= 513.343     M2= 1.77669
A1= 90.          A2= 24          A3= 90          C/H= .318212
B2= 49.8852      W2= 830.306     W3= 784.274     MR2= 1.18404
UM= 592.933      UTIP= 682.146   DIA.= 6.51401   H= .928577
T3= 1660         HT3= 2.11359    S3= 2.58926     V3= 8.4482      Q3= .818773
STAGE EFF.= .651812              ETT= .806222    ETS= .703015

TURBINE TOTAL ENTHALPY DROP= .378699        OVERALL CYCLE EFFICIENCY = .79059
OVERALL TURBINE EFFICIENCY= .698728

NEW WEIGHT FLOW= 6.87432

NUMBER OF STAGES= 3                 RPM= 24000
INITIAL WEIGHT FLOW= 6.583

STAGE NO.-- 1
T1= 2610         HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 37.3518      DS= 1.79831     CO= 1144.79     H/D= 5.53976 E-2
C1= 300          C2= 1060.85     C3= 268.435     M2= 1.16461
A1= 90.          A2= 16.75       A3= 90          C/H= .942889
B2= 29.4758      W2= 621.335     W3= 545.537     MR2= .682107
UM= 474.927      UTIP= 501.917   DIA.= 4.79295   H= .265518
T3= 2249         HT3= 2.35303    S3= 2.5135      V3= 1.06918     Q3= .93682
STAGE EFF.= .723644              ETT= .777839    ETS= .735071

STAGE NO.-- 2
T1= 2249         HT1= 2.35303    S1= 2.5135      V1= 1.06918     Q1= .93682
NS= 57.8097      DS= 1.2058      CO= 1157.99     H/D= 9.32262 E-2
C1= 268.435      C2= 1076.99     C3= 373.851     M2= 1.3017
A1= 90.          A2= 22          A3= 90          C/H= .507867
B2= 37.8977      W2= 656.811     W3= 608.627     MR2= .793852
UM= 480.276      UTIP= 526.876   DIA.= 5.0313    H= .469049
T3= 1940         HT3= 2.22467    S3= 2.54353     V3= 2.65071     Q3= .871397
STAGE EFF.= .687801              ETT= .798066    ETS= .714884

STAGE NO.-- 3
T1= 1940         HT1= 2.22467    S1= 2.54353     V1= 2.65071     Q1= .871397
NS= 96.1979      DS= .801517     CO= 1211.19     H/D= .207493
C1= 373.851      C2= 1128.7      C3= 454.944     M2= 1.50554
A1= 90.          A2= 25          A3= 90          C/H= .213757
B2= 42.3349      W2= 708.295     W3= 675.529     MR2= .944771
UM= 499.368      UTIP= 609.565   DIA.= 5.82092   H= 1.2078
T3= 1660         HT3= 2.09684    S3= 2.58447     V3= 8.39875     Q3= .813974
STAGE EFF.= .652917              ETT= .810769    ETS= .696378

TURBINE TOTAL ENTHALPY DROP= .395442        OVERALL CYCLE EFFICIENCY = .79556
OVERALL TURBINE EFFICIENCY= .717975

NEW WEIGHT FLOW= 6.58326
```

Table 13. (continued)

```
NUMBER OF STAGES= 4                  RPM= 24000
INITIAL WEIGHT FLOW= 6.425

STAGE NO.-- 1
T1= 2610        HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 40.9353     DS= 1.65177     CO= 1002.7      H/D= 6.06875 E-2
C1= 300         C2= 930.004     C3= 255.825     M2= .999893
A1= 90.         A2= 18          A3= 90
B2= 31.5563     W2= 549.142     W3= 488.832     MR2= .59041
UM= 416.548     UTIP= 442.538   DIA.= 4.22592   H= .256461
T3= 2328        HT3= 2.38392    S3= 2.50682     V3= .88412      Q3= .952414
STAGE EFF.= .741962             ETT= .782879    ETS= .731919

STAGE NO.-- 2
T1= 2328        HT1= 2.38392    S1= 2.50682     V1= .88412      Q1= .952414
NS= 56.1713     DS= 1.24029     CO= 996.555     H/D= 9.06928 E-2
C1= 255.825     C2= 926.46      C3= 311.707     M2= 1.06786
A1= 90.         A2= 21.375      A3= 90
B2= 36.9686     W2= 561.489     W3= 518.322     MR2= .647185
UM= 414.124     UTIP= 453.179   DIA.= 4.32754   H= .392477
T3= 2091        HT3= 2.28476    S3= 2.52598     V3= 1.6343      Q3= .901482
STAGE EFF.= .712271             ETT= .797028    ETS= .719851

STAGE NO.-- 3
T1= 2091        HT1= 2.28476    S1= 2.52598     V1= 1.6343      Q1= .901482
NS= 77.2214     DS= .945619     CO= 1030.69     H/D= .145014
C1= 311.707     C2= 959.868     C3= 368.896     M2= 1.18983
A1= 90.         A2= 24          A3= 90
B2= 40.8899     W2= 596.408     W3= 563.536     MR2= .73929
UM= 426.018     UTIP= 491.259   DIA.= 4.69118   H= .680287
T3= 1869        HT3= 2.18658    S3= 2.55045     V3= 3.41708     Q3= .85424
STAGE EFF.= .682223             ETT= .806453    ETS= .703145

STAGE NO.-- 4
T1= 1869        HT1= 2.18658    S1= 2.55045     V1= 3.41708     Q1= .85424
NS= 114.066     DS= .715683     CO= 1071.41     H/D= .279527
C1= 368.896     C2= 998.763     C3= 412.146     M2= 1.33426
A1= 90.         A2= 25.5        A3= 90
B2= 43.0507     W2= 629.871     W3= 603.748     MR2= .841453
UM= 441.191     UTIP= 570.901   DIA.= 5.4517    H= 1.5239
T3= 1660        HT3= 2.08722    S3= 2.58215     V3= 8.37479     Q3= .811649
STAGE EFF.= .653795             ETT= .813275    ETS= .692929

TURBINE TOTAL ENTHALPY DROP= .405065      OVERALL CYCLE EFFICIENCY = .7999L
OVERALL TURBINE EFFICIENCY= .727826

NEW WEIGHT FLOW= 6.42687

NUMBER OF STAGES= 5                  RPM= 24000
INITIAL WEIGHT FLOW= 6.306

STAGE NO.-- 1
T1= 2610        HT1= 2.49228    S1= 2.4909      V1= .52288      Q1= 1
NS= 44.5594     DS= 1.52811     CO= 906.824     H/D= 6.69477 E-2
C1= 300         C2= 841.667     C3= 246.69      M2= .894116
A1= 90.         A2= 19          A3= 90
B2= 33.1973     W2= 500.471     W3= 450.554     MR2= .531658
UM= 377.023     UTIP= 403.039   DIA.= 3.84873   H= .257664
T3= 2378        HT3= 2.40298    S3= 2.50293     V3= .789524     Q3= .962326
STAGE EFF.= .754733             ETT= .787173    ETS= .728919

STAGE NO.-- 2
T1= 2378        HT1= 2.40298    S1= 2.50293     V1= .789524     Q1= .962326
NS= 57.4432     DS= 1.21204     CO= 895.244     H/D= 9.21979 E-2
C1= 246.69      C2= 832.626     C3= 288.92      M2= .933645
A1= 90.         A2= 22          A3= 90
B2= 37.8928     W2= 507.837     W3= 470.41      MR2= .569451
UM= 371.239     UTIP= 406.842   DIA.= 3.88505   H= .358194
T3= 2183        HT3= 2.32165    S3= 2.51678     V3= 1.26247     Q3= .919712
STAGE EFF.= .729021             ETT= .797838    ETS= .71474

STAGE NO.-- 3
T1= 2183        HT1= 2.32165    S1= 2.51678     V1= 1.26247     Q1= .919712
NS= 72.3737     DS= .99976      CO= 918.71      H/D= .132427
C1= 288.92      C2= 855.162     C3= 317.457     M2= 1.01617
A1= 90.         A2= 23.25       A3= 90
B2= 39.8169     W2= 527.175     W3= 495.766     MR2= .626428
UM= 380.796     UTIP= 433.895   DIA.= 4.14339   H= .548695
T3= 1999        HT3= 2.24056    S3= 2.53398     V3= 2.16578     Q3= .880154
STAGE EFF.= .702229             ETT= .804873    ETS= .708769

STAGE NO.-- 4
T1= 1999        HT1= 2.24056    S1= 2.53398     V1= 2.16578     Q1= .880154
NS= 95.7137     DS= .804223     CO= 937.6       H/D= .205645
C1= 317.457     C2= 873.747     C3= 352.137     M2= 1.10032
A1= 90.         A2= 25          A3= 90
B2= 42.3332     W2= 548.319     W3= 522.89      MR2= .690503
UM= 386.544     UTIP= 471.084   DIA.= 4.49852   H= .925097
T3= 1826        HT3= 2.161      S3= 2.55467     V3= 4.02642     Q3= .843589
STAGE EFF.= .677977             ETT= .810684    ETS= .696333

STAGE NO.-- 5
T1= 1826        HT1= 2.161      S1= 2.55467     V1= 4.02642     Q1= .843589
NS= 131.34      DS= .664318     CO= 968.647     H/D= .384635
C1= 352.137     C2= 902.753     C3= 367.974     M2= 1.20714
A1= 90.         A2= 25.125      A3= 90
B2= 42.5883     W2= 566.408     W3= 543.756     MR2= .757387
UM= 400.329     UTIP= 551.657   DIA.= 5.26793   H= 2.02623
T3= 1660        HT3= 2.0795     S3= 2.58072     V3= 8.36006     Q3= .810219
STAGE EFF.= .653369             ETT= .815085    ETS= .697458

TURBINE TOTAL ENTHALPY DROP= .412789      OVERALL CYCLE EFFICIENCY = .80313
OVERALL TURBINE EFFICIENCY= .734638

NEW WEIGHT FLOW= 6.30661
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Table 13. (continued)

```
NUMBER OF STAGES= 1                    RPM= 24000
INITIAL WEIGHT FLOW= 8.255

STAGE NO.-- 1
T1= 2460        HT1= 2.48032   S1= 2.51952    V1= .730224    Q1= 1
NS= 58.7992     DS= 1.1917     CO= 1835.48    H/D= 9.68835 E-2
C1= 300         C2= 1706.81    C3= 586.136    M2= 2.23291
A1= 90.         A2= 21.75      A3= 90         C/H= .491
B2= 37.5492     W2= 1037.78    W3= 961.755    MR2= 1.35767
UM= 762.513     UTIP= 839.496  DIA.= 8.0166   H= .776676
T3= 1660        HT3= 2.16791   S3= 2.6145     V3= 8.70853    Q3= .844035
STAGE EFF.= .664548            ETT= .798657   ETS= .717214

TURBINE TOTAL ENTHALPY DROP= .312414      OVERALL CYCLE EFFICIENCY = .79866
OVERALL TURBINE EFFICIENCY= .66458

NEW WEIGHT FLOW= 8.33285

NUMBER OF STAGES= 2                    RPM= 24090
INITIAL WEIGHT FLOW= 7.55

STAGE NO.-- 1
T1= 2460        HT1= 2.48032   S1= 2.51952    V1= .730224    Q1= 1
NS= 45.2506     DS= 1.50725    CO= 1315.1     H/D= 6.83586 E-2
C1= 300         C2= 1220.71    C3= 360.683    M2= 1.41289
A1= 90.         A2= 19.125     A3= 90         C/H= .732725
B2= 33.4043     W2= 726.439    W3= 655.127    MR2= .840801
UM= 543.906     UTIP= 585.461  DIA.= 5.59074  H= .382175
T3= 2023        HT3= 2.30256   S3= 2.55438    V3= 2.07419    Q3= .915656
STAGE EFF.= .715253            ETT= .78791    ETS= .728644

STAGE NO.-- 2
T1= 2023        HT1= 2.30256   S1= 2.55438    V1= 2.07419    Q1= .915656
NS= 87.5456     DS= .862712    CO= 1361.02    H/D= .179981
C1= 360.683     C2= 1267.61    C3= 491.656    M2= 1.66891
A1= 90.         A2= 24.125     A3= 90         C/H= .251155
B2= 41.1153     W2= 787.904    0P747.678   MR2= 1.03734
UM= 563.294     UTIP= 670.957  DIA.= 6.40717  H= 1.15317
T3= 1660        HT3= 2.13555   S3= 2.60453    V3= 8.60573    Q3= .83406
STAGE EFF.= .667336            ETT= .80909    ETS= .703508

TURBINE TOTAL ENTHALPY DROP= .344777      OVERALL CYCLE EFFICIENCY = .79850
OVERALL TURBINE EFFICIENCY= .709542

NEW WEIGHT FLOW= 7.55068

NUMBER OF STAGES= 3                    RPM= 24000
INITIAL WEIGHT FLOW= 7.24

STAGE NO.-- 1
T1= 2460        HT1= 2.48032   S1= 2.51952    V1= .730224    Q1= 1
NS= 48.4186     DS= 1.41717    CO= 1087.65    H/D= 7.43614 E-2
C1= 300         C2= 1010.12    C3= 312.203    M2= 1.12211
A1= 90.         A2= 19.875     A3= 90
B2= 34.6116     W2= 604.579    W3= 549.64     MR2= .671609
UM= 452.369     UTIP= 487.141  DIA.= 4.65185  H= .345918
T3= 2156        HT3= 2.35513   S3= 2.53921    V3= 1.40097    Q3= .943327
STAGE EFF.= .742189            ETT= .791019   ETS= .725845

STAGE NO.-- 2
T1= 2156        HT1= 2.35513   S1= 2.53921    V1= 1.40097    Q1= .943327
NS= 70.643      DS= 1.01611    CO= 1110.17    H/D= .125972
C1= 312.203     C2= 1033.55    C3= 387.509    M2= 1.25197
A1= 90.         A2= 23.5       A3= 90
B2= 40.1528     W2= 639.127    W3= 600.949    MR2= .774193
UM= 459.326     UTIP= 520.154  DIA.= 4.9671   H= .625717
T3= 1896        HT3= 2.23681   S3= 2.5655     V3= 3.17133    Q3= .882124
STAGE EFF.= .703604            ETT= .804243   ETS= .706255

STAGE NO.-- 3
T1= 1896        HT1= 2.23681   S1= 2.5655     V1= 3.17133    Q1= .882124
NS= 110.841     DS= .728142    CO= 1144.77    H/D= .264764
C1= 387.509     C2= 1067.15    C3= 440.126    M2= 1.40898
A1= 90.         A2= 25.5       A3= 90
B2= 43.043      W2= 673.095    W3= 644.827    MR2= .8887
UM= 471.269     UTIP= 603.067  DIA.= 5.75886  H= 1.52474
T3= 1660        HT3= 2.12078   S3= 2.60013    V3= 8.5603     Q3= .82965
STAGE EFF.= .66872             ETT= .812888   ETS= .69273

TURBINE TOTAL ENTHALPY DROP= .359549      OVERALL CYCLE EFFICIENCY = .80272
OVERALL TURBINE EFFICIENCY= .728754

NEW WEIGHT FLOW= 7.24045
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Table 13. (continued)

```
NUMBER OF STAGES= 4                  RPM= 24000
INITIAL WEIGHT FLOW= 7.045

STAGE NO.-- 1
T1= 2460        HT1= 2.48032    S1= 2.51952     V1= .730224     Q1= 1
NS= 55.2485     DS= 1.3006      CO= 953.805     H/D= 8.42198 E-2
C1= 300         C2= 886.416     C3= 290.1       M2= .96486
A1= 90.         A2= 20.875      A3= 90          C/H= .574967
B2= 36.1902     W2= 534.925     W3= 491.304     MR2= .582264
UM= 396.515     UTIP= 431.161   DIA.= 4.11728   H= .346757
T3= 2223        HT3= 2.38293    S3= 2.53322     V3= 1.17432     Q3= .958402
STAGE EFF.= .759182             ETT= .794994    ETS= .721451

STAGE NO.-- 2
T1= 2223        HT1= 2.38293    S1= 2.53322     V1= 1.17432     Q1= .958402
NS= 69.7976     DS= 1.02557     CO= 960.692     H/D= .123351
C1= 290.1       C2= 894.388     C3= 335.168     M2= 1.03866
A1= 90.         A2= 23.5        A3= 90          C/H= .371819
B2= 40.1459     W2= 553.15      W3= 519.851     MR2= .642375
UM= 397.378     UTIP= 448.871   DIA.= 4.2864    H= .528731
T3= 2023        HT3= 2.29134    S3= 2.5502      V3= 2.06169     Q3= .910107
STAGE EFF.= .727204             ETT= .803917    ETS= .706066

STAGE NO.-- 3
T1= 2023        HT1= 2.29134    S1= 2.5502      V1= 2.06169     Q1= .910107
NS= 93.3965     DS= .817616     CO= 983.97      H/D= .196919
C1= 335.168     C2= 916.959     C3= 369.33      M2= 1.13564
A1= 90.         A2= 25          A3= 90          C/H= .225271
B2= 42.3248     W2= 575.529     W3= 548.509     MR2= .712786
UM= 405.536     UTIP= 490.447   DIA.= 4.68342   H= .922255
T3= 1836        HT3= 2.20124    S3= 2.57152     V3= 3.96641     Q3= .866588
STAGE EFF.= .697132             ETT= .810264    ETS= .69611

STAGE NO.-- 4
T1= 1836        HT1= 2.20124    S1= 2.57152     V1= 3.96641     Q1= .866588
NS= 132.09      DS= .662337     CO= 1008.57     H/D= .390828
C1= 369.33      C2= 939.96      C3= 383.184     M2= 1.24234
A1= 90.         A2= 25.125      A3= 90          C/H= .113024
B2= 42.5899     W2= 589.735     W3= 566.214     MR2= .779448
UM= 416.852     UTIP= 575.949   DIA.= 5.4999    H= 2.14952
T3= 1660        HT3= 2.11082    S3= 2.59852     V3= 8.5437      Q3= .82804
STAGE EFF.= .668618             ETT= .815163    ETS= .697498

TURBINE TOTAL ENTHALPY DROP= .369504      OVERALL CYCLE EFFICIENCY = .80608
OVERALL TURBINE EFFICIENCY= .738035

NEW WEIGHT FLOW= 7.04539
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Table 14. Calculation of the Effects of Number of Stages and RPM on the Size and Performance of Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic and Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses.

```
NUMBER OF STAGES= 3                RPM= 18000
INITIAL WEIGHT FLOW= 1.966

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.894       V1= 2.774       Q1= 1
NS= 14.0175     DS= 4.09137     CO= 2107.93     H/D= 1.42808 E-2
C1= 500         C2= 1950.88     C3= 354.967     M2= 1.13592
A1= 90.         A2= 15          A3= 90
B2= 24.5283     W2= 1216.27     W3= 655.057     MR2= .708184
UM= 777.899     UTIP= 789.086   DIA.= 10.047    H= .143478
T3= 2300        HT3= 9.18337    S3= 8.00219     V3= 5.59595     Q3= .959709
STAGE EFF.= .645469             ETT= .67363     ETS= .654527

STAGE NO.-- 2
T1= 2300        HT1= 9.18337    S1= 8.00219     V1= 5.59595     Q1= .959709
NS= 21.2811     DS= 2.92689     CO= 2118.43     H/D= .024871
C1= 354.967     C2= 1960.6      C3= 404.602     M2= 1.23428
A1= 90.         A2= 15          A3= 90
B2= 25.7152     W2= 1169.49     W3= 932.476     MR2= .736244
UM= 840.129     UTIP= 861.276   DIA.= 10.9661   H= .272738
T3= 2036        HT3= 8.74194    S3= 8.11537     V3= 13.0916     Q3= .904694
STAGE EFF.= .657006             ETT= .732561    ETS= .705839

STAGE NO.-- 3
T1= 2036        HT1= 8.74194    S1= 8.11537     V1= 13.0916     Q1= .904694
NS= 24.6123     DS= 1.92926     CO= 2168.57     H/D= 5.15487 E-2
C1= 404.602     C2= 2008.1      C3= 472.867     M2= 1.37524
A1= 90.         A2= 15.75       A3= 90
B2= 27.7755     W2= 1169.68     W3= 1014.71     MR2= .801047
UM= 897.802     UTIP= 945.203   DIA.= 12.0347   H= .620373
T3= 1790        HT3= 8.29215    S3= 8.2529      V3= 37.1489     Q3= .851259
STAGE EFF.= .646222             ETT= .773354    ETS= .736582

TURBINE TOTAL ENTHALPY DROP= 1.32419       OVERALL CYCLE EFFICIENCY = .72652
OVERALL TURBINE EFFICIENCY= .676021

NEW WEIGHT FLOW= 1.96595

NUMBER OF STAGES= 5                RPM= 18000
INITIAL WEIGHT FLOW= 1.8845

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984      V1= 2.774       Q1= 1
NS= 16.8296     DS= 3.54598     CO= 1663.13     H/D= 1.79293 E-2
C1= 500         C2= 1539.22     C3= 298.077     M2= .87216
A1= 90.         A2= 15          A3= 90
B2= 25.1        W2= 939.133     W3= 702.68      MR2= .532134
UM= 636.328     UTIP= 647.838   DIA.= 8.24852   H= .14789
T3= 2412        HT3= 9.33116    S3= 7.95233     V3= 4.13314     Q3= .977581
STAGE EFF.= .685575             ETT= .702266    ETS= .679708

STAGE NO.-- 2
T1= 2412        HT1= 9.33116    S1= 7.95233     V1= 4.13314     Q1= .977581
NS= 21.6962     DS= 2.88007     CO= 1632.8      H/D= .025591
C1= 298.077     C2= 1511.15     C3= 313.241     M2= .896225
A1= 90.         A2= 15          A3= 90
B2= 25.7595     W2= 899.95      W3= 720.765     MR2= .533737
UM= 649.143     UTIP= 665.962   DIA.= 8.47929   H= .216993
T3= 2246        HT3= 9.05613    S3= 8.00753     V3= 6.5001      Q3= .94297
STAGE EFF.= .689319             ETT= .734726    ETS= .707685

STAGE NO.-- 3
T1= 2246        HT1= 9.05613    S1= 8.00753     V1= 6.5001      Q1= .94297
NS= 27.4919     DS= 2.35742     CO= 1652.48     H/D= 3.69125 E-2
C1= 313.241     C2= 1529.36     C3= 331.898     M2= .951659
A1= 90.         A2= 15          A3= 90
B2= 26.2258     W2= 895.719     W3= 751.048     MR2= .557369
UM= 673.739     UTIP= 699.048   DIA.= 8.90055   H= .328542
T3= 2087        HT3= 8.77878    S3= 8.06974     V3= 10.8186     Q3= .908365
STAGE EFF.= .681134             ETT= .757385    ETS= .726832

STAGE NO.-- 4
T1= 2087        HT1= 8.77878    S1= 8.06974     V1= 10.8186     Q1= .908365
NS= 36.0059     DS= 1.86047     CO= 1671.87     H/D= 5.35274 E-2
C1= 331.898     C2= 1548.72     C3= 378.317     M2= 1.01286
A1= 90.         A2= 16.25       A3= 90
B2= 28.6308     W2= 904.445     W3= 789.534     MR2= .591502
UM= 692.997     UTIP= 731.021   DIA.= 9.30765   H= .498214
T3= 1935        HT3= 8.50336    S3= 8.14036     V3= 19.2182     Q3= .874624
STAGE EFF.= .668323             ETT= .77571     ETS= .73599

STAGE NO.-- 5
T1= 1935        HT1= 8.50336    S1= 8.14036     V1= 19.2182     Q1= .874624
NS= 48.6934     DS= 1.40929     CO= 1696.85     H/D= 7.47001 E-2
C1= 378.317     C2= 1576.02     C3= 490.474     M2= 1.08557
A1= 90.         A2= 20          A3= 90
B2= 34.8053     W2= 944.359     W3= 859.292     MR2= .65048
UM= 705.567     UTIP= 760.055   DIA.= 9.67732   H= .722897
T3= 1790        HT3= 8.23473    S3= 8.21935     V3= 36.7474     Q3= .842051
STAGE EFF.= .65524              ETT= .791271    ETS= .725161

TURBINE TOTAL ENTHALPY DROP= 1.38162       OVERALL CYCLE EFFICIENCY = .75227
OVERALL TURBINE EFFICIENCY= .706288

NEW WEIGHT FLOW= 1.88424
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Table 14. (continued)

```
NUMBER OF STAGES= 7                    RPM= 18000
INITIAL WEIGHT FLOW= 1.843

STAGE NO.-- 1
T1= 2610        HT1= 9.61235    S1= 7.8984      V1= 2.774       Q1= 1
NS= 19.6659     DS= 3.12475     CO= 1429.5      H/D= 2.21872 E-2
C1= 500         C2= 1323.       C3= 267.778     M2= .741373
A1= 90.         A2= 15          A3= 90
B2= 25.5241     W2= 794.671     W3= 621.452     MR2= .445312
UM= 560.805     UTIP= 573.382   DIA.= 7.30053   H= .161978
T3= 2460        HT3= 9.39428    S3= 7.93325     V3= 3.66443     Q3= .985291
STAGE EFF.= .711757             ETT= .723199    ETS= .697822

STAGE NO.-- 2
T1= 2460        HT1= 9.39428    S1= 7.93325     V1= 3.66443     Q1= .985291
NS= 24.3237     DS= 2.61597     CO= 1373.35     H/D= 3.04319 E-2
C1= 267.778     C2= 1271.03     C3= 269.889     M2= .735427
A1= 90.         A2= 15          A3= 90
B2= 26.0022     W2= 750.371     W3= 615.616     MR2= .434169
UM= 553.306     UTIP= 570.392   DIA.= 7.26245   H= .22101
T3= 2340        HT3= 9.19318    S3= 7.96772     V3= 4.9708      Q3= .959808
STAGE EFF.= .713785             ETT= .74654     ETS= .717709

STAGE NO.-- 3
T1= 2340        HT1= 9.19318    S1= 7.96772     V1= 4.9708      Q1= .959808
NS= 28.298      DS= 2.30001     CO= 1387.27     H/D= 3.86712 E-2
C1= 269.889     C2= 1283.91     C3= 279.911     M2= .768264
A1= 90.         A2= 15          A3= 90
B2= 26.2734     W2= 750.697     W3= 632.342     MR2= .4492
UM= 567.02      UTIP= 589.353   DIA.= 7.50387   H= .290184
T3= 2223        HT3= 8.99101    S3= 8.00581     V3= 6.93448     Q3= .934286
STAGE EFF.= .704766             ETT= .759687    ETS= .728759

STAGE NO.-- 4
T1= 2223        HT1= 8.99101    S1= 8.00581     V1= 6.93448     Q1= .934286
NS= 33.4463     DS= 1.99167     CO= 1401.31     H/D= .050149
C1= 279.911     C2= 1297.15     C3= 294.283     M2= .803652
A1= 90.         A2= 15.25       A3= 90
B2= 26.9206     W2= 753.586     W3= 649.981     MR2= .466887
UM= 579.548     UTIP= 609.298   DIA.= 7.75782   H= .389047
T3= 2109        HT3= 8.7887     S3= 8.04818     V3= 9.98448     Q3= .908997
STAGE EFF.= .693613             ETT= .771253    ETS= .737239

STAGE NO.-- 5
T1= 2109        HT1= 8.7887     S1= 8.04818     V1= 9.98448     Q1= .908997
NS= 40.51       DS= 1.65643     CO= 1405.34     H/D= 5.68664 E-2
C1= 294.283     C2= 1304.37     C3= 378.951     M2= .83717
A1= 90.         A2= 19          A3= 90
B2= 33.088      W2= 777.867     W3= 694.142     MR2= .499252
UM= 581.579     UTIP= 615.528   DIA.= 7.83714   H= .44567
T3= 2000        HT3= 8.59427    S3= 8.09325     V3= 14.7739     Q3= .884177
STAGE EFF.= .683293             ETT= .782217    ETS= .725341

STAGE NO.-- 6
T1= 2000        HT1= 8.59427    S1= 8.09325     V1= 14.7739     Q1= .884177
NS= 48.3519     DS= 1.4188      CO= 1443.29     H/D= 7.41841 E-2
C1= 378.951     C2= 1340.4      C3= 414.241     M2= .892227
A1= 90.         A2= 19.875      A3= 90
B2= 34.6103     W2= 802.287     W3= 729.306     MR2= .534038
UM= 600.248     UTIP= 646.274   DIA.= 8.22861   H= .610432
T3= 1893        HT3= 8.39512    S3= 8.14494     V3= 22.7986     Q3= .860184
STAGE EFF.= .676503             ETT= .790959    ETS= .725803

STAGE NO.-- 7
T1= 1893        HT1= 8.39512    S1= 8.14494     V1= 22.7986     Q1= .860184
NS= 60.1924     DS= 1.16714     CO= 1459.44     H/D= .100033
C1= 414.241     C2= 1357.36     C3= 472.225     M2= .937889
A1= 90.         A2= 22          A3= 90
B2= 37.9274     W2= 827.242     W3= 768.265     MR2= .571596
UM= 606.003     UTIP= 669.24    DIA.= 8.52102   H= .852383
T3= 1790        HT3= 8.19971    S3= 8.20131     V3= 36.5315     Q3= .837101
STAGE EFF.= .659503             ETT= .799456    ETS= .715757

TURBINE TOTAL ENTHALPY DROP= 1.41264       OVERALL CYCLE EFFICIENCY = .76762
OVERALL TURBINE EFFICIENCY= .722616

NEW WEIGHT FLOW= 1.84286
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Table 14. (continued)

```
NUMBER OF STAGES= 9               RPM= 18000
INITIAL WEIGHT FLOW= 1.814

STAGE NO.-- 1
T1= 2610         HT1= 9.61635   S1= 7.8984     V1= 2.774        Q1= 1
NS= 22.1745      DS= 2.82798    CO= 1283.66    H/D= 2.64357 E-2
C1= 500          C2= 1188.02    C3= 247.47     M2= .661177
A1= 90.          A2= 15         A3= 90         C/H= 2.04327
B2= 25.8084      W2= 706.267    W3= 568.418    MR2= .393062
UM= 511.723      UTIP= 525.425  DIA.= 6.68991  H= .176853
T3= 2488         HT3= 9.43644   S3= 7.92496    V3= 3.42744      Q3= .990766
STAGE EFF.= .729723             ETT= .73711    ETS= .709715

STAGE NO.-- 2
T1= 2488         HT1= 9.43644   S1= 7.92496    V1= 3.42744      Q1= .990766
NS= 27.0266      DS= 2.39197    CO= 1215.44    H/D= 3.59174 E-2
C1= 247.47       C2= 1124.89    C3= 243.436    M2= .641854
A1= 90.          A2= 15         A3= 90         C/H= 1.49891
B2= 26.1968      W2= 659.504    W3= 551.436    MR2= .376309
UM= 494.797      UTIP= 512.875  DIA.= 6.53013  H= .234545
T3= 2393         HT3= 9.27532   S3= 7.9497     V3= 4.32214      Q3= .970197
STAGE EFF.= .731247             ETT= .75598    ETS= .725655

STAGE NO.-- 3
T1= 2393         HT1= 9.27532   S1= 7.9497     V1= 4.32214      Q1= .970197
NS= 30.3268      DS= 2.16798    CO= 1222.55    H/D= 4.32918 E-2
C1= 243.436      C2= 1131.47    C3= 249.201    M2= .662619
A1= 90.          A2= 15         A3= 90         C/H= 1.24162
B2= 26.3798      W2= 659.084    W3= 560.858    MR2= .385979
UM= 502.459      UTIP= 524.659  DIA.= 6.68016  H= .289196
T3= 2300         HT3= 9.11451   S3= 7.97657    V3= 5.53812      Q3= .949744
STAGE EFF.= .722416             ETT= .764826   ETS= .733047

STAGE NO.-- 4
T1= 2300         HT1= 9.11451   S1= 7.97657    V1= 5.53812      Q1= .949744
NS= 34.4889      DS= 1.93256    CO= 1224.65    H/D= 5.05033 E-2
C1= 249.201      C2= 1134.23    C3= 271.336    M2= .682052
A1= 90.          A2= 16         A3= 90         C/H= 1.04728
B2= 28.174       W2= 662.153    W3= 574.679    MR2= .398175
UM= 506.595      UTIP= 532.787  DIA.= 6.79365  H= .342597
T3= 2210         HT3= 8.9565    S3= 8.00534    V3= 7.1995       Q3= .929605
STAGE EFF.= .713051             ETT= .7731[illegible]   ETS= .735179

STAGE NO.-- 5
T1= 2210         HT1= 8.9565    S1= 8.00534    V1= 7.1995       Q1= .929605
NS= 39.0932      DS= 1.72387    CO= 1227.03    H/D= 5.79025 E-2
C1= 271.336      C2= 1146.83    C3= 302.799    M2= .707369
A1= 90.          A2= 17.375     A3= 90         C/H= .892641
B2= 30.5217      W2= 674.335    W3= 596.218    MR2= .415932
UM= 513.606      UTIP= 544.146  DIA.= 6.92828  H= .401165
T3= 2122         HT3= 8.79941   S3= 8.03664    V3= 9.53349      Q3= .909673
STAGE EFF.= .702804             ETT= .780396   ETS= .733607

STAGE NO.-- 6
T1= 2122         HT1= 8.79941   S1= 8.03664    V1= 9.53349      Q1= .909673
NS= 44.6762      DS= 1.51983    CO= 1251.06    H/D= 6.57705 E-2
C1= 302.799      C2= 1161.57    C3= 349.768    M2= .737762
A1= 90.          A2= 19.5       A3= 90         C/H= .756633
B2= 33.9625      W2= 694.065    W3= 626.092    MR2= .440829
UM= 519.287      UTIP= 554.473  DIA.= 7.05977  H= .464324
T3= 2036         HT3= 8.64408   S3= 8.07046    V3= 12.8795      Q3= .890009
STAGE EFF.= .692836             ETT= .787293   ETS= .725756

STAGE NO.-- 7
T1= 2036         HT1= 8.64408   S1= 8.07046    V1= 12.8795      Q1= .890009
NS= 51.2965      DS= 1.34011    CO= 1270.42    H/D= 7.85462 E-2
C1= 349.768      C2= 1180.76    C3= 387.834    M2= .771328
A1= 90.          A2= 21         A3= 90         C/H= .615304
B2= 36.3417      W2= 714.051    W3= 654.461    MR2= .466451
UM= 527.171      UTIP= 570.04   DIA.= 7.25797  H= .570087
T3= 1952         HT3= 8.48883   S3= 8.10743    V3= 17.7799      Q3= .870869
STAGE EFF.= .682669             ETT= .793484   ETS= .719535

STAGE NO.-- 8
T1= 1952         HT1= 8.48883   S1= 8.10743    V1= 17.7799      Q1= .870869
NS= 59.7456      DS= 1.17532    CO= 1287.9     H/D= 9.91769 E-2
C1= 387.834      C2= 1197.71    C3= 414.092    M2= .805071
A1= 90.          A2= 21.875     A3= 90         C/H= .478404
B2= 37.7417      W2= 729.038    W3= 676.505    MR2= .490041
UM= 534.969      UTIP= 590.3    DIA.= 7.51593  H= .745406
T3= 1870         HT3= 8.33347   S3= 8.14792    V3= 25.1284      Q3= .852404
STAGE EFF.= .672316             ETT= .799203   ETS= .716582

STAGE NO.-- 9
T1= 1870         HT1= 8.33347   S1= 8.14792    V1= 25.1284      Q1= .852404
NS= 70.6425      DS= 1.01612    CO= 1303.4     H/D= .125971
C1= 414.092      C2= 1213.45    C3= 454.958    M2= .839873
A1= 90.          A2= 23.5       A3= 90         C/H= .36405
B2= 40.1528      W2= 750.372    W3= 705.549    MR2= .51936
UM= 539.276      UTIP= 610.689  DIA.= 7.77553  H= .97949
T3= 1790         HT3= 8.17982   S3= 8.19159    V3= 36.4152      Q3= .834434
STAGE EFF.= .662888             ETT= .804243   ETS= .706255

TURBINE TOTAL ENTHALPY DROP= 1.43652      OVERALL CYCLE EFFICIENCY = .77739
OVERALL TURBINE EFFICIENCY= .732404

NEW WEIGHT FLOW= 1.81222
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Table 14. (continued)

```
NUMBER OF STAGES= 3                 RPM= 18000
INITIAL WEIGHT FLOW= 1.697

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984      V1= 2.774       Q1= 1
NS= 12.3964     DS= 4.48754     CO= 2286.08     H/D= 1.24343 E-2
C1= 500         C2= 2115.71     C3= 366.817     M2= 1.24635
A1= 90.         A2= 15          A3= 90          C/H= 4.40454
B2= 24.1859     W2= 1340.72     W3= 898.139     MR2= .789812
UM= 819.816     UTIP= 830.073   DIA.= 10.5688   H= .131416
T3= 2251        HT3= 9.12511    S3= 8.03009     V3= 6.46701     Q3= .95321
STAGE EFF.= .621013             ETT= .652118    ETS= .635327

STAGE NO.-- 2
T1= 2251        HT1= 9.12511    S1= 8.03009     V1= 6.46701     Q1= .95321
NS= 20.7505     DS= 2.98903     CO= 2310.89     H/D= 2.39687 E-2
C1= 366.817     C2= 2138.72     C3= 438.725     M2= 1.38315
A1= 90.         A2= 15          A3= 90          C/H= 2.25647
B2= 25.6558     W2= 1278.49     W3= 1013.3      MR2= .826823
UM= 913.401     UTIP= 935.549   DIA.= 11.9118   H= .28551
T3= 1945        HT3= 8.61102    S3= 8.17701     V3= 18.718      Q3= .889653
STAGE EFF.= .642687             ETT= .729657    ETS= .703358

STAGE NO.-- 3
T1= 1945        HT1= 8.61102    S1= 8.17701     V1= 18.718      Q1= .889653
NS= 39.2133     DS= 1.71939     CO= 2393.99     H/D= 5.82056 E-2
C1= 438.725     C2= 2219.43     C3= 586.18      M2= 1.59334
A1= 90.         A2= 17.375      A3= 90          C/H= .887959
B2= 30.5254     W2= 1304.88     W3= 1154.08     MR2= .936782
UM= 994.132     UTIP= 1053.56   DIA.= 13.4144   H= .780791
T3= 1660        HT3= 8.0815     S3= 8.36231     V3= 74.319      Q3= .827762
STAGE EFF.= .632566             ETT= .780563    ETS= .733765

TURBINE TOTAL ENTHALPY DROP= 1.53484         OVERALL CYCLE EFFICIENCY = .72078
OVERALL TURBINE EFFICIENCY= .665895

NEW WEIGHT FLOW= 1.69613

NUMBER OF STAGES= 5                 RPM= 18000
INITIAL WEIGHT FLOW= 1.6245

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984      V1= 2.774       Q1= 1
NS= 14.4696     DS= 3.99284     CO= 1798.76     H/D= 1.48291 E-2
C1= 500         C2= 1664.75     C3= 306.453     M2= .949803
A1= 90.         A2= 15          A3= 90          C/H= 3.6779
B2= 24.6327     W2= 1033.75     W3= 735.253     MR2= .589795
UM= 668.346     UTIP= 678.329   DIA.= 8.63675   H= .128075
T3= 2381        HT3= 9.29412    S3= 7.96732     V3= 4.48395     Q3= .973432
STAGE EFF.= .66011              ETT= .678902    ETS= .659197

STAGE NO.-- 2
T1= 2381        HT1= 9.29412    S1= 7.96732     V1= 4.48395     Q1= .973432
NS= 19.4804     DS= 3.14922     CO= 1772.85     H/D= 2.18909 E-2
C1= 306.453     C2= 1640.76     C3= 331.276     M2= .987897
A1= 90.         A2= 15          A3= 90          C/H= 2.47386
B2= 25.5001     W2= 986.407     W3= 769.498     MR2= .593911
UM= 694.541     UTIP= 709.908   DIA.= 9.03883   H= .197868
T3= 2188        HT3= 8.97805    S3= 8.03827     V3= 7.78107     Q3= .933831
STAGE EFF.= .670671             ETT= .722018    ETS= .696807

STAGE NO.-- 3
T1= 2188        HT1= 8.97805    S1= 8.03827     V1= 7.78107     Q1= .933831
NS= 26.0999     DS= 2.46409     CO= 1803.13     H/D= 3.39797 E-2
C1= 331.276     C2= 1668.79     C3= 358.994     M2= 1.06392
A1= 90.         A2= 15          A3= 90          C/H= 1.58522
B2= 26.1353     W2= 980.526     W3= 814.981     MR2= .625121
UM= 731.657     UTIP= 756.925   DIA.= 9.63747   H= .327479
T3= 2004        HT3= 8.65517    S3= 8.11925     V3= 14.6957     Q3= .893957
STAGE EFF.= .665498             ETT= .753003    ETS= .723155

STAGE NO.-- 4
T1= 2004        HT1= 8.65517    S1= 8.11925     V1= 14.6957     Q1= .893957
NS= 36.7452     DS= 1.82099     CO= 1837.66     H/D= 5.31673 E-2
C1= 358.994     C2= 1703.22     C3= 436.831     M2= 1.15359
A1= 90.         A2= 17          A3= 90          C/H= .97877
B2= 29.8525     W2= 1000.41     W3= 877.573     MR2= .677575
UM= 761.134     UTIP= 802.61    DIA.= 10.2191   H= .543324
T3= 1828        HT3= 8.33191    S3= 8.21324     V3= 30.834      Q3= .855074
STAGE EFF.= .652923             ETT= .776888    ETS= .73299

STAGE NO.-- 5
T1= 1828        HT1= 8.33191    S1= 8.21324     V1= 30.834      Q1= .855074
NS= 54.6337     DS= 1.26754     CO= 1883.57     H/D= 8.60144 E-2
C1= 436.831     C2= 1751.23     C3= 591.733     M2= 1.26547
A1= 90.         A2= 21.5        A3= 90          C/H= .556151
B2= 37.1285     W2= 1063.33     W3= 980.332     MR2= .768375
UM= 781.608     UTIP= 851.402   DIA.= 10.8404   H= .932429
T3= 1660        HT3= 8.01423    S3= 8.32118     V3= 73.4002     Q3= .817525
STAGE EFF.= .639396             ETT= .79599     ETS= .717431

TURBINE TOTAL ENTHALPY DROP= 1.60211         OVERALL CYCLE EFFICIENCY = .74536
OVERALL TURBINE EFFICIENCY= .695386

NEW WEIGHT FLOW= 1.62492
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Table 14. (continued)

```
NUMBER OF STAGES= 7                    RPM= 18000
INITIAL WEIGHT FLOW= 1.585

STAGE NO.-- 1
T1= 2610         HT1= 9.61635   S1= 7.8984     V1= 2.774        Q1= 1
NS= 16.756       DS= 3.55842    CO= 1543.54    H/D= 1.78265 E-2
C1= 500          C2= 1428.55    C3= 276.271    M2= .804313
A1= 90.          A2= 15         A3= 90         C/H= 3.04825
B2= 25.9872      W2= 872.02     W3= 651.578    MR2= .490973
UM= 590.113      UTIP= 600.725  DIA.= 7.64866  H= .136349
T3= 2436         HT3= 9.3695    S3= 7.9457     V3= 3.89419      Q3= .982725
STAGE EFF.= .688786             ETT= .70163    ETS= .679154

STAGE NO.-- 2
T1= 2436         HT1= 9.3695    S1= 7.9457     V1= 3.89419      Q1= .982725
NS= 21.3026      DS= 2.92442    CO= 1485.43    H/D= .024908
C1= 276.271      C2= 1374.94    C3= 283.808    M2= .803706
A1= 90.          A2= 15         A3= 90         C/H= 2.17025
B2= 25.7176      W2= 820.077    W3= 654.032    MR2= .479366
UM= 589.249      UTIP= 604.104  DIA.= 7.69168  H= .191584
T3= 2297         HT3= 9.13954   S3= 7.98943    V3= 5.61193      Q3= .953722
STAGE EFF.= .69598              ETT= .732675   ETS= .705937

STAGE NO.-- 3
T1= 2297         HT1= 9.13954   S1= 7.98943    V1= 5.61193      Q1= .953722
NS= 26.5972      DS= 2.50517    CO= 1504.54    H/D= 3.29535 E-2
C1= 283.808      C2= 1392.45    C3= 298.513    M2= .846802
A1= 90.          A2= 15         A3= 90         C/H= 1.63508
B2= 26.0998      W2= 819.192    W3= 678.534    MR2= .498182
UM= 609.346      UTIP= 629.745  DIA.= 8.01816  H= .264226
T3= 2162         HT3= 8.90669   S3= 8.03801    V3= 8.41628      Q3= .924447
STAGE EFF.= .689141             ETT= .75126    ETS= .721706

STAGE NO.-- 4
T1= 2162         HT1= 8.90669   S1= 8.03801    V1= 8.41628      Q1= .924447
NS= 31.3234      DS= 2.10861    CO= 1530.39    H/D= .045574
C1= 298.513      C2= 1416.41    C3= 314.       M2= .897795
A1= 90.          A2= 15.0313    A3= 90         C/H= 1.17845
B2= 25.4768      W2= 823.934    W3= 704.293    MR2= .522254
UM= 630.429      UTIP= 659.78   DIA.= 8.40058  H= .382848
T3= 2030         HT3= 8.67023   S3= 8.09325    V3= 13.2638      Q3= .895236
STAGE EFF.= .678283             ETT= .767045   ETS= .734755

STAGE NO.-- 5
T1= 2030         HT1= 8.67023   S1= 8.09325    V1= 13.2638      Q1= .895236
NS= 39.7115      DS= 1.69484    CO= 1545.35    H/D= 5.76259 E-2
C1= 314.         C2= 1433.3     C3= 393.1      M2= .948252
A1= 90.          A2= 18         A3= 90         C/H= .887572
B2= 31.5206      W2= 847.188    W3= 751.903    MR2= .560486
UM= 640.967      UTIP= 678.894  DIA.= 8.64394  H= .498115
T3= 1903         HT3= 8.43878   S3= 8.154      V3= 21.9498      Q3= .86665
STAGE EFF.= .666903             ETT= .781249   ETS= .730696

STAGE NO.-- 6
T1= 1903         HT1= 8.43878   S1= 8.154      V1= 21.9498      Q1= .86665
NS= 50.6811      DS= 1.35964    CO= 1587.4     H/D= 7.88384 E-2
C1= 393.1        C2= 1474.75    C3= 469.182    M2= 1.02044
A1= 90.          A2= 20.375     A3= 90         C/H= .620319
B2= 35.4044      W2= 886.263    W3= 809.849    MR2= .613243
UM= 660.099      UTIP= 713.984  DIA.= 9.09073  H= .716698
T3= 1779         HT3= 8.205     S3= 8.22345    V3= 38.7502      Q3= .838906
STAGE EFF.= .65423              ETT= .792986   ETS= .723711

STAGE NO.-- 7
T1= 1779         HT1= 8.205     S1= 8.22345    V1= 38.7502      Q1= .838906
NS= 67.5         DS= 1.05947    CO= 1619.24    H/D= .119126
C1= 469.182      C2= 1506.74    C3= 545.498    M2= 1.09227
A1= 90.          A2= 22.75      A3= 90         C/H= .391015
B2= 39.0737      W2= 924.407    W3= 865.43     MR2= .670124
UM= 671.868      UTIP= 755.848  DIA.= 9.62375  H= 1.14644
T3= 1660         HT3= 7.97308   S3= 8.30131    V3= 72.9564      Q3= .812581
STAGE EFF.= .642176             ETT= .802991   ETS= .711858

TURBINE TOTAL ENTHALPY DROP= 1.64327       OVERALL CYCLE EFFICIENCY = .76141
OVERALL TURBINE EFFICIENCY= .710729

NEW WEIGHT FLOW= 1.58422
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Table 14. (continued)

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NUMBER OF STAGES= 9                RPM= 18000
INITIAL WEIGHT FLOW= 1.558

STAGE NO.-- 1
T1= 2610          HT1= 9.61635   S1= 7.8984     V1= 2.774       Q1= 1
NS= 18.836        DS= 3.23728    CO= 1381.53    H/D= 2.08812 E-2
C1= 500           C2= 1278.61    C3= 255.854    M2= .714487
A1= 90.           A2= 15         A3= 90         C/H= 2.59536
B2= 25.4129       W2= 771.143    W3= 596.198    MR2= .430916
UM= 538.512       UTIP= 549.871  DIA.= 7.00118  H= .146193
T3= 2469          HT3= 9.4134    S3= 7.93301    V3= 3.58958     Q3= .980097
STAGE EFF.= .708575              ETT= .717731   ETS= .693115

STAGE NO.-- 2
T1= 2469          HT1= 9.4134    S1= 7.93301    V1= 3.58958     Q1= .988097
NS= 23.3458       DS= 2.70823    CO= 1312.66    H/D= 2.85732 E-2
C1= 255.854       C2= 1214.86    C3= 255.853    M2= .698893
A1= 90.           A2= 15         A3= 90         C/H= 1.88865
B2= 25.9189       W2= 719.353    W3= 585.343    MR2= .413834
UM= 526.469       UTIP= 541.72   DIA.= 6.89739  H= .19708
T3= 2359          HT3= 9.2295    S3= 7.96424    V3= 4.7299      Q3= .964768
STAGE EFF.= .714006              ETT= .742493   ETS= .714285

STAGE NO.-- 3
T1= 2359          HT1= 9.2295    S1= 7.96424    V1= 4.7299      Q1= .964768
NS= 26.6963       DS= 2.41716    CO= 1326.77    H/D= 3.52199 E-2
C1= 255.853       C2= 1227.92    C3= 265.184    M2= .728382
A1= 90.           A2= 15         A3= 90         C/H= 1.52888
B2= 26.1755       W2= 720.454    W3= 601.156    MR2= .427362
UM= 539.508       UTIP= 558.831  DIA.= 7.11526  H= .250598
T3= 2251          HT3= 9.04402   S3= 7.9985     V3= 6.38654     Q3= .941301
STAGE EFF.= .706329              ETT= .754947   ETS= .724788

STAGE NO.-- 4
T1= 2251          HT1= 9.04402   S1= 7.9985     V1= 6.38654     Q1= .941301
NS= 31.2105       DS= 2.11512    CO= 1330.71    H/D= 4.53029 E-2
C1= 265.184       C2= 1231.6     C3= 272.899    M2= .753721
A1= 90.           A2= 15.0313    A3= 90         C/H= 1.18556
B2= 26.4717       W2= 716.557    W3= 612.214    MR2= .438522
UM= 548.031       UTIP= 573.391  DIA.= 7.30064  H= .33074
T3= 2147          HT3= 8.86016   S3= 8.03562    V3= 8.80722     Q3= .918239
STAGE EFF.= .69756               ETT= .766802   ETS= .734553

STAGE NO.-- 5
T1= 2147          HT1= 8.86016   S1= 8.03562    V1= 8.80722     Q1= .918239
NS= 36.5483       DS= 1.83443    CO= 1346.38    H/D= 5.41339 E-2
C1= 272.899       C2= 1247.43    C3= 310.063    M2= .788458
A1= 90.           A2= 16.5       A3= 90         C/H= .968927
B2= 29.0499       W2= 729.634    W3= 638.55     MR2= .461175
UM= 558.221       UTIP= 589.205  DIA.= 7.50199  H= .406112
T3= 2045          HT3= 8.67695   S3= 8.07646    V3= 12.509      Q3= .895285
STAGE EFF.= .686857              ETT= .776586   ETS= .7384

STAGE NO.-- 6
T1= 2045          HT1= 8.67695   S1= 8.07646    V1= 12.509      Q1= .895285
NS= 43.1641       DS= 1.56965    CO= 1369.44    H/D= 6.33859 E-2
C1= 310.063       C2= 1271.04    C3= 371.504    M2= .830601
A1= 90.           A2= 19         A3= 90         C/H= .792403
B2= 33.1627       W2= 756.484    W3= 679.142    MR2= .494347
UM= 568.528       UTIP= 605.619  DIA.= 7.71097  H= .488767
T3= 1945          HT3= 8.49442   S3= 8.12141    V3= 18.3594     Q3= .872588
STAGE EFF.= .676174              ETT= .785603   ETS= .727788

STAGE NO.-- 7
T1= 1945          HT1= 8.49442   S1= 8.12141    V1= 18.3594     Q1= .872588
NS= 51.835        DS= 1.32857    CO= 1392.53    H/D= 7.99844 E-2
C1= 371.504       C2= 1294.23    C3= 425.411    M2= .875075
A1= 90.           A2= 21         A3= 90         C/H= .604167
B2= 36.3511       W2= 782.396    W3= 717.711    MR2= .529072
UM= 578.048       UTIP= 625.941  DIA.= 7.96973  H= .637454
T3= 1848          HT3= 8.31256   S3= 8.17082    V3= 27.8368     Q3= .850698
STAGE EFF.= .665708              ETT= .793917   ETS= .719821

STAGE NO.-- 8
T1= 1848          HT1= 8.31256   S1= 8.17082    V1= 27.8368     Q1= .850698
NS= 63.0637       DS= 1.12228    CO= 1422.84    H/D= .107574
C1= 425.411       C2= 1323.54    C3= 466.931    M2= .926994
A1= 90.           A2= 22.25      A3= 90         C/H= .437599
B2= 38.3187       W2= 808.272    W3= 753.071    MR2= .566105
UM= 590.844       UTIP= 657.307  DIA.= 8.36908  H= .900298
T3= 1753          HT3= 8.12864   S3= 8.22614    V3= 43.9553     Q3= .829573
STAGE EFF.= .654524              ETT= .800961   ETS= .714702

STAGE NO.-- 9
T1= 1753          HT1= 8.12884   S1= 8.22614    V1= 43.9553     Q1= .829573
NS= 78.7916       DS= .933885    CO= 1450.19    H/D= .151306
C1= 466.931       C2= 1350.33    C3= 513.819    M2= .981073
A1= 90.           A2= 23.75      A3= 90         C/H= .301291
B2= 40.5547       W2= 836.453    W3= 790.279    MR2= .60772
UM= 600.447       UTIP= 696.513  DIA.= 8.86827  H= 1.34182
T3= 1660          HT3= 7.94489   S3= 8.28747    V3= 72.6472     Q3= .809136
STAGE EFF.= .64375               ETT= .806912   ETS= .705616

TURBINE TOTAL ENTHALPY DROP= 1.67146        OVERALL CYCLE EFFICIENCY = .77177
OVERALL TURBINE EFFICIENCY= .721295

NEW WEIGHT FLOW= 1.5575
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Table 14. (continued)

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NUMBER OF STAGES= 3                    RPM= 18000
INITIAL WEIGHT FLOW= 1.869

STAGE NO.-- 1
T1= 2460        HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 16.2441     DS= 3.64736     CO= 2178.05     H/D= 1.71228 E-2
C1= 500         C2= 2015.77     C3= 386.023     M2= 1.21225
A1= 90.         A2= 15          A3= 90          C/H= 3.17591
B2= 24.9952     W2= 1234.72     W3= 913.574     MR2= .742535
UM= 828.014     UTIP= 842.311   DIA.= 10.7246   H= .183636
T3= 2158        HT3= 9.03783    S3= 8.0993      V3= 8.72036     Q3= .944764
STAGE EFF.= .656389             ETT= .697056    ETS= .67516

STAGE NO.-- 2
T1= 2158        HT1= 9.03783    S1= 8.0993      V1= 8.72036     Q1= .944764
NS= 26.2821     DS= 2.44955     CO= 2176.11     H/D= .034356
C1= 386.023     C2= 2013.98     C3= 433.778     M2= 1.31696
A1= 90.         A2= 15          A3= 90          C/H= 1.56769
B2= 26.1478     W2= 1182.82     W3= 984.317     MR2= .773456
UM= 883.586     UTIP= 914.444   DIA.= 11.6431   H= .40001
T3= 1900        HT3= 8.57142    S3= 8.2257      V3= 22.7668     Q3= .886818
STAGE EFF.= .660104             ETT= .753608    ETS= .723663

STAGE NO.-- 3
T1= 1900        HT1= 8.57142    S1= 8.2257      V1= 22.7668     Q1= .886818
NS= 45.9995     DS= 1.4842      CO= 2226.24     H/D= 6.95429 E-2
C1= 433.778     C2= 2066.82     C3= 619.751     M2= 1.48008
A1= 90.         A2= 19.375      A3= 90          C/H= .716925
B2= 33.8033     W2= 1232.45     W3= 1113.97     MR2= .882577
UM= 925.663     UTIP= 992.081   DIA.= 12.6316   H= .878436
T3= 1660        HT3= 8.11408    S3= 8.37815     V3= 74.6727     Q3= .831703
STAGE EFF.= .643752             ETT= .788689    ETS= .727567

TURBINE TOTAL ENTHALPY DROP= 1.39237       OVERALL CYCLE EFFICIENCY = .74645
OVERALL TURBINE EFFICIENCY= .671358

NEW WEIGHT FLOW= 1.8697

NUMBER OF STAGES= 5                    RPM= 18000
INITIAL WEIGHT FLOW= 1.796

STAGE NO.-- 1
T1= 2460        HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 19.2365     DS= 3.18198     CO= 1716.49     H/D= 2.15052 E-2
C1= 500         C2= 1588.6      C3= 319.685     M2= .926824
A1= 90.         A2= 15          A3= 90          C/H= 2.5189
B2= 25.4677     W2= 956.18      W3= 743.448     MR2= .557855
UM= 671.209     UTIP= 685.795   DIA.= 8.73181   H= .18778
T3= 2267        HT3= 9.19988    S3= 8.04732     V3= 6.22899     Q3= .965465
STAGE EFF.= .693719             ETT= .720431    ETS= .6[illegible]5441

STAGE NO.-- 2
T1= 2267        HT1= 9.19988    S1= 8.04732     V1= 6.22899     Q1= .965465
NS= 25.6728     DS= 2.4989      CO= 1676.98     H/D= 3.31067 E-2
C1= 319.685     C2= 1552.04     C3= 332.901     M2= .951338
A1= 90.         A2= 15          A3= 90          C/H= 1.62744
B2= 26.1052     W2= 912.904     W3= 756.556     MR2= .559573
UM= 679.381     UTIP= 702.232   DIA.= 8.94109   H= .29601
T3= 2105        HT3= 8.90919    S3= 8.10863     V3= 10.346      Q3= .928273
STAGE EFF.= .692521             ETT= .751544    ETS= .721928

STAGE NO.-- 3
T1= 2105        HT1= 8.90919    S1= 8.10863     V1= 10.346      Q1= .928273
NS= 33.6304     DS= 1.98237     CO= 1696.17     H/D= 5.06115 E-2
C1= 332.901     C2= 1570.09     C3= 356.441     M2= 1.01287
A1= 90.         A2= 15.25       A3= 90          C/H= 1.05697
B2= 26.9276     W2= 911.934     W3= 787.076     MR2= .588292
UM= 701.744     UTIP= 738.105   DIA.= 9.39785   H= .475639
T3= 1950        HT3= 8.61883    S3= 8.17885     V3= 18.3704     Q3= .892131
STAGE EFF.= .679504             ETT= .77159     ETS= .737517

STAGE NO.-- 4
T1= 1950        HT1= 8.61883    S1= 8.17885     V1= 18.3704     Q1= .892131
NS= 45.6166     DS= 1.49587     CO= 1721.89     H/D= .068928
C1= 356.441     C2= 1598.45     C3= 475.791     M2= 1.08799
A1= 90.         A2= 19.25       A3= 90          C/H= .725
B2= 33.6042     W2= 952.19      W3= 859.677     MR2= .648114
UM= 716.015     UTIP= 766.923   DIA.= 9.76477   H= .673066
T3= 1801        HT3= 8.33581    S3= 8.25797     V3= 35.3594     Q3= .856992
STAGE EFF.= .665119             ETT= .788294    ETS= .728106

STAGE NO.-- 5
T1= 1801        HT1= 8.33581    S1= 8.25797     V1= 35.3594     Q1= .856992
NS= 63.9012     DS= 1.10948     CO= 1759.26     H/D= .109614
C1= 475.791     C2= 1636.62     C3= 581.075     M2= 1.17757
A1= 90.         A2= 22.375      A3= 90          C/H= .428345
B2= 38.5062     W2= 1000.65     W3= 933.303     MR2= .719983
UM= 730.352     UTIP= 814.118   DIA.= 10.3657   H= 1.13622
T3= 1660        HT3= 8.05714    S3= 8.34819     V3= 74.0036     Q3= .824249
STAGE EFF.= .650429             ETT= .801372    ETS= .713946

TURBINE TOTAL ENTHALPY DROP= 1.44931       OVERALL CYCLE EFFICIENCY = .76665
OVERALL TURBINE EFFICIENCY= .696391

NEW WEIGHT FLOW= 1.79624
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Table 14. (continued)

```
NUMBER OF STAGES= 7                    RPM= 18000
INITIAL WEIGHT FLOW= 1.758

STAGE NO.-- 1
T1= 2460         HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 22.3479      DS= 2.80957     CO= 1475.11     H/D= 2.67461 E-2
C1= 500          C2= 1365.21     C3= 284.866     M2= .786211
A1= 90.          A2= 15          A3= 90          C/H= 2.01927
B2= 25.8256      W2= 811.099     W3= 653.908     MR2= .467104
UM= 588.602      UTIP= 604.549   DIA.= 7.69735   H= .205874
T3= 2314         HT3= 9.27275    S3= 8.02886     V3= 5.45103     Q3= .975027
STAGE EFF.= .717936              ETT= .737947    ETS= .710427

STAGE NO.-- 2
T1= 2314         HT1= 9.27275    S1= 8.02886     V1= 5.45103     Q1= .975027
NS= 28.3199      DS= 2.29849     CO= 1410.98     H/D= 3.87197 E-2
C1= 284.866      C2= 1305.86     C3= 284.73      M2= .778775
A1= 90.          A2= 15          A3= 90          C/H= 1.3895
B2= 26.2747      W2= 763.497     W3= 643.202     MR2= .455326
UM= 576.751      UTIP= 599.496   DIA.= 7.63302   H= .295549
T3= 2197 ,       HT3= 9.0603     S3= 8.06723     V3= 7.66091     Q3= .947573
STAGE EFF.= .715926              ETT= .759747    ETS= .728809

STAGE NO.-- 3
T1= 2197         HT1= 9.0603     S1= 8.06723     V1= 7.66091     Q1= .947573
NS= 33.5537      DS= 1.98624     CO= 1428.78     H/D= 5.04185 E-2
C1= 284.73       C2= 1322.57     C3= 300.167     M2= .817922
A1= 90.          A2= 15.25       A3= 90          C/H= 1.06104
B2= 26.9247      W2= 768.248     W3= 662.883     MR2= .47511
UM= 591.03       UTIP= 621.536   DIA.= 7.91363   H= .398993
T3= 2082         HT3= 8.84702    S3= 8.11042     V3= 11.1662     Q3= .920276
STAGE EFF.= .703409              ETT= .77145     ETS= .737402

STAGE NO.-- 4
T1= 2082         HT1= 8.84702    S1= 8.11042     V1= 11.1662     Q1= .920276
NS= 40.7441      DS= 1.65958     CO= 1439.33     H/D= 6.05772 E-2
C1= 300.167      C2= 1334.86     C3= 364.396     M2= .856716
A1= 90.          A2= 17.875      A3= 90          C/H= .845816
B2= 31.3556      W2= 787.398     W3= 700.291     MR2= .505355
UM= 598.019      UTIP= 635.262   DIA.= 8.0884    H= .489973
T3= 1971         HT3= 8.6388     S3= 8.15762     V3= 16.8322     Q3= .893631
STAGE EFF.= .691145              ETT= .782629    ETS= .732466

STAGE NO.-- 5
T1= 1971         HT1= 8.6388     S1= 8.15762     V1= 16.8322     Q1= .893631
NS= 50.0589      DS= 1.37486     CO= 1454.23     H/D= 7.75608 E-2
C1= 364.396      C2= 1350.91     C3= 426.695     M2= .900107
A1= 90.          A2= 20.25       A3= 90          C/H= .632082
B2= 35.2063      W2= 811.02      W3= 740.117     MR2= .540381
UM= 604.741      UTIP= 653.283   DIA.= 8.31786   H= .64514
T3= 1865         HT3= 8.43488    S3= 8.2093      V3= 26.2055     Q3= .868311
STAGE EFF.= .67903               ETT= .792465    ETS= .724239

STAGE NO.-- 6
T1= 1865         HT1= 8.43488    S1= 8.2093      V1= 26.2055     Q1= .868311
NS= 61.4838      DS= 1.14282     CO= 1496.2      H/D= .102045
C1= 426.695      C2= 1392.02     C3= 496.1       M2= .964747
A1= 90.          A2= 22.5        A3= 90          C/H= .459139
B2= 38.6587      W2= 852.758     W3= 794.166     MR2= .591011
UM= 620.153      UTIP= 686.211   DIA.= 8.73711   H= .891578
T3= 1760         HT3= 8.22865    S3= 8.26803     V3= 43.0549     Q3= .843518
STAGE EFF.= .666137              ETT= .800155    ETS= .712186

STAGE NO.-- 7
T1= 1760         HT1= 8.22865    S1= 8.26803     V1= 43.0549     Q1= .843518
NS= 78.8656      DS= .933241     CO= 1515.86     H/D= .151554
C1= 496.1        C2= 1411.47     C3= 537.103     M2= 1.018
A1= 90.          A2= 23.75       A3= 90          C/H= .300795
B2= 48.5551      W2= 874.321     W3= 826.083     MR2= .630586
UM= 627.647      UTIP= 728.234   DIA.= 9.27216   H= 1.40524
T3= 1660         HT3= 8.02461    S3= 8.3332      V3= 73.6688     Q3= .820518
STAGE EFF.= .653497              ETT= .806933    ETS= .705627

TURBINE TOTAL ENTHALPY DROP= 1.48183       OVERALL CYCLE EFFICIENCY = .77876
OVERALL TURBINE EFFICIENCY= .709415

NEW WEIGHT FLOW= 1.75681
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Table 14. (continued)

```
NUMBER OF STAGES= 9                  RPM= 18000
INITIAL WEIGHT FLOW= 1.73

STAGE NO.-- 1
T1= 2460        HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 25.1805     DS= 2.54033     CO= 1322.1      H/D= .032116
C1= 500         C2= 1223.6      C3= 261.531     M2= .699505
A1= 90.         A2= 15          A3= 90          C/H= 1.67816
B2= 26.0691     W2= 720.647     W3= 595.122     MR2= .411976
UM= 534.579     UTIP= 552.014   DIA.= 7.02846   H= .225726
T3= 2341        HT3= 9.31491    S3= 8.01905     V3= 5.06324     Q3= .980609
STAGE EFF.= .733888             ETT= .74979     ETS= .720451

STAGE NO.-- 2
T1= 2341        HT1= 9.31491    S1= 8.01905     V1= 5.06324     Q1= .980609
NS= 31.15       DS= 2.11863     CO= 1251.01     H/D= 4.51577 E-2
C1= 261.531     C2= 1157.84     C3= 256.487     M2= .680347
A1= 90.         A2= 15.0313     A3= 90          C/H= 1.1894
B2= 26.469      W2= 673.705     W3= 575.453     MR2= .395871
UM= 515.136     UTIP= 538.896   DIA.= 6.86143   H= .309847
T3= 2248        HT3= 9.1445     S3= 8.04688     V3= 6.56454     Q3= .958455
STAGE EFF.= .731495             ETT= .76667     ETS= .734443

STAGE NO.-- 3
T1= 2248        HT1= 9.1445     S1= 8.04688     V1= 6.56454     Q1= .958455
NS= 35.7731     DS= 1.87077     CO= 1250.47     H/D= 5.29454 E-2
C1= 256.487     C2= 1158.36     C3= 282.755     M2= .699869
A1= 90.         A2= 16.25       A3= 90          C/H= .994754
B2= 28.6226     W2= 676.651     W3= 590.253     MR2= .408826
UM= 518.123     UTIP= 546.236   DIA.= 6.95488   H= .368229
T3= 2158        HT3= 8.97824    S3= 8.07666     V3= 8.64641     Q3= .936727
STAGE EFF.= .721172             ETT= .775329    ETS= .735687

STAGE NO.-- 4
T1= 2158        HT1= 8.97824    S1= 8.07666     V1= 8.64641     Q1= .936727
NS= 40.8303     DS= 1.65537     CO= 1263.       H/D= 6.04217 E-2
C1= 282.755     C2= 1171.91     C3= 322.28      M2= .728448
A1= 90.         A2= 18          A3= 90          C/H= .846205
B2= 31.5534     W2= 692.037     W3= 615.882     MR2= .430165
UM= 524.827     UTIP= 557.426   DIA.= 7.09737   H= .428835
T3= 2070        HT3= 8.81358    S3= 8.10915     V3= 11.62       Q3= .915349
STAGE EFF.= .709973             ETT= .782744    ETS= .731817

STAGE NO.-- 5
T1= 2070        HT1= 8.81358    S1= 8.10915     V1= 11.62       Q1= .915349
NS= 46.917      DS= 1.45376     CO= 1280.23     H/D= 7.00496 E-2
C1= 322.287     C2= 1189.06     C3= 368.989     M2= .760811
A1= 90.         A2= 20          A3= 90          C/H= .703611
B2= 34.7686     W2= 713.147     W3= 647.048     MR2= .456301
UM= 531.53      UTIP= 569.953   DIA.= 7.25687   H= .508341
T3= 1984        HT3= 8.65037    S3= 8.14459     V3= 15.9596     Q3= .894459
STAGE EFF.= .698944             ETT= .789601    ETS= .724007

STAGE NO.-- 6
T1= 1984        HT1= 8.65037    S1= 8.14459     V1= 15.9596     Q1= .894459
NS= 54.4201     DS= 1.27162     CO= 1299.26     H/D= 8.54295 E-2
C1= 368.989     C2= 1207.98     C3= 408.069     M2= .795955
A1= 90.         A2= 21.5        A3= 90          C/H= .559983
B2= 37.1252     W2= 733.522     W3= 676.103     MR2= .483329
UM= 539.073     UTIP= 586.872   DIA.= 7.47229   H= .638353
T3= 1900        HT3= 8.48772    S3= 8.18342     V3= 22.4445     Q3= .87425
STAGE EFF.= .687948             ETT= .795839    ETS= .717334

STAGE NO.-- 7
T1= 1900        HT1= 8.48772    S1= 8.18342     V1= 22.4445     Q1= .87425
NS= 63.9581     DS= 1.1067      CO= 1318.32     H/D= .109784
C1= 408.069     C2= 1226.42     C3= 435.452     M2= .83265
A1= 90.         A2= 22.375      A3= 90          C/H= .427675
B2= 38.5068     W2= 749.839     W3= 699.4       MR2= .509088
UM= 547.307     UTIP= 610.181   DIA.= 7.76906   H= .85292
T3= 1818        HT3= 8.32491    S3= 8.2262      V3= 32.3859     Q3= .854824
STAGE EFF.= .676711             ETT= .801399    ETS= .713963

STAGE NO.-- 8
T1= 1818        HT1= 8.32491    S1= 8.2262      V1= 32.3859     Q1= .854824
NS= 76.5015     DS= .952236     CO= 1334.28     H/D= .14266
C1= 435.452     C2= 1242.61     C3= 477.401     M2= .869928
A1= 90.         A2= 24          A3= 90          C/H= .317967
B2= 40.8854     W2= 772.154     W3= 729.358     MR2= .540573
UM= 551.413     UTIP= 634.444   DIA.= 8.07798   H= 1.1524
T3= 1738        HT3= 8.16414    S3= 8.27248     V3= 48.0384     Q3= .836015
STAGE EFF.= .666511             ETT= .806233    ETS= .703021

STAGE NO.-- 9
T1= 1738        HT1= 8.16414    S1= 8.27248     V1= 48.0384     Q1= .836015
NS= 92.4729     DS= .828613     CO= 1354.69     H/D= .196793
C1= 477.401     C2= 1261.91     C3= 495.309     M2= .911492
A1= 90.         A2= 24.375      A3= 90          C/H= .228429
B2= 41.4771     W2= 786.327     W3= 747.838     MR2= .567971
UM= 560.301     UTIP= 677.539   DIA.= 8.6267    H= 1.69767
T3= 1660        HT3= 8.00234    S3= 8.32383     V3= 73.4594     Q3= .818185
STAGE EFF.= .654959             ETT= .810094    ETS= .701[illegible]8

TURBINE TOTAL ENTHALPY DROP= 1.5041        OVERALL [illegible] EFFICIENCY = .78641
OVERALL TURBINE EFFICIENCY= .717772

NEW WEIGHT FLOW= 1.7308
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Table 14. (continued)

```
NUMBER OF STAGES= 3                    RPM= 24000
INITIAL WEIGHT FLOW= 1.9325

STAGE NO.-- 1
T1= 2610        HT1= 9.61635   S1= 7.894      V1= 2.774      Q1= 1
NS= 18.4891     DS= 3.28677    CO= 2107.93    H/D= .02035
C1= 500         C2= 1950.88    C3= 388.382    M2= 1.13872
A1= 90.         A2= 15         A3= 90
B2= 25.3634     W2= 1178.74    W3= 906.677    MR2= .688025
UM= 819.285     UTIP= 836.123  DIA.= 7.98438  H= .162482
T3= 2360        HT3= 9.16202   S3= 7.99123    V3= 5.57121    Q3= .955445
STAGE EFF.= .681199            ETT= .715296   ETS= .691013

STAGE NO.-- 2
T1= 2300        HT1= 9.16202   S1= 7.99123    V1= 5.57121    Q1= .955445
NS= 28.0159     DS= 2.31976    CO= 2119.89    H/D= 3.80508 E-2
C1= 388.382     C2= 1961.95    C3= 427.065    M2= 1.23929
A1= 90.         A2= 15         A3= 90
B2= 26.2571     W2= 1147.81    W3= 965.33     MR2= .725023
UM= 865.73      UTIP= 899.271  DIA.= 8.5874   H= .326757
T3= 2036        HT3= 8.70999   S3= 8.09825    V3= 13.0107    Q3= .899096
STAGE EFF.= .674695            ETT= .7589     ETS= .7281

STAGE NO.-- 3
T1= 2036        HT1= 8.70999   S1= 8.09825    V1= 13.0107    Q1= .899096
NS= 45.6346     DS= 1.49538    CO= 2166.63    H/D= 6.89748 E-2
C1= 427.065     C2= 2011.3     C3= 598.702    M2= 1.38325
A1= 90.         A2= 19.25      A3= 90
B2= 33.6046     W2= 1198.11    W3= 1081.74    MR2= .823992
UM= 900.966     UTIP= 965.069  DIA.= 9.21572  H= .635653
T3= 1790        HT3=[ 8.26909  S3= 8.22831    V3= 36.8546    Q3= .844511
STAGE EFF.= .654383            ETT= .788313   ETS= .728119

TURBINE TOTAL ENTHALPY DROP= 1.34726     OVERALL CYCLE EFFICIENCY = . 75417
OVERALL TURBINE EFFICIENCY= .695233

NEW WEIGHT FLOW= 1.9323

NUMBER OF STAGES= 5                    RPM= 24000
INITIAL WEIGHT FLOW= 1.8575

STAGE NO.-- 1
T1= 2610        HT1= 9.61635   S1= 7.8984     V1= 2.774      Q1= 1
NS= 22.2508     DS= 2.81986    CO= 1663.13    H/D= 2.65719 E-2
C1= 500         C2= 1539.22    C3= 320.87     M2= .873364
A1= 90.         A2= 15         A3= 90         C/H= 2.03266
B2= 25.816      W2= 914.801    W3= 736.808    MR2= .519063
UM= 663.276     UTIP= 681.128  DIA.= 6.50429  H= .172832
T3= 2412        HT3= 9.31939   S3= 7.94654    V3= 4.123      Q3= .975167
STAGE EFF.= .717599            ETT= .73748    ETS= .71003

STAGE NO.-- 2
T1= 2412        HT1= 9.31939   S1= 7.94654    V1= 4.123      Q1= .975167
NS= 28.6024     DS= 2.2791     CO= 1635.22    H/D= .039347
C1= 320.87      C2= 1513.39    C3= 330.486    M2= .89943
A1= 90.         A2= 15         A3= 90         C/H= 1.36716
B2= 26.2906     W2= 884.339    W3= 746.142    MR2= .525574
UM= 668.965     UTIP= 695.782  DIA.= 6.64422  H= .26143
T3= 2246        HT3= 9.03652   S3= 7.99803    V3= 6.47559    Q3= .9394
STAGE EFF.= .70979             ETT= .760515   ETS= .729451

STAGE NO.-- 3
T1= 2246        HT1= 9.03652   S1= 7.99803    V1= 6.47559    Q1= .9394
NS= 36.2925     DS= 1.84669    CO= 1652.89    H/D= 5.38688 E-2
C1= 330.486     C2= 1531.28    C3= 377.354    M2= .955313
A1= 90.         A2= 16.375     A3= 90         C/H= .97566
B2= 28.8411     W2= 894.937    W3= 782.267    MR2= .55832
UM= 685.238     UTIP= 723.081  DIA.= 6.90491  H= .371959
T3= 2087        HT3= 8.75725   S3= 8.05702    V3= 10.7674    Q3= .904061
STAGE EFF.= .69398             ETT= .776175   ETS= .735721

STAGE NO.-- 4
T1= 2087        HT1= 8.75725   S1= 8.05702    V1= 10.7674    Q1= .904061
NS= 47.2763     DS= 1.44815    CO= 1677.79    H/D= 7.21192 E-2
C1= 377.354     C2= 1557.91    C3= 474.401    M2= 1.02198
A1= 90.         A2= 19.625     A3= 90         C/H= .688008
B2= 34.2105     W2= 930.647    W3= 843.775    MR2= .610502
UM= 697.789     UTIP= 749.763  DIA.= 7.1597   H= .516352
T3= 1935        HT3= 8.48454   S3= 8.12406    V3= 19.1091    Q3= .869655
STAGE EFF.= .677649            ETT= .78995    ETS= .726794

STAGE NO.-- 5
T1= 1935        HT1= 8.48454   S1= 8.12406    V1= 19.1091    Q1= .869655
NS= 63.173      DS= 1.11958    CO= 1716.4     H/D= .107442
C1= 474.401     C2= 1596.75    C3= 566.602    M2= 1.1033
A1= 90.         A2= 22.375     A3= 90         C/H= .437048
B2= 38.4987     W2= 976.434    W3= 910.207    MR2= .674687
UM= 712.352     UTIP= 792.381  DIA.= 7.56668  H= .812979
T3= 1790        HT3= 8.21486   S3= 8.20126    V3= 36.5309    Q3= .837089
STAGE EFF.= .661175            ETT= .801019   ETS= .71373

TURBINE TOTAL ENTHALPY DROP= 1.40148     OVERALL CYCLE EFFICIENCY = .77303
OVERALL TURBINE EFFICIENCY= .721053

NEW WEIGHT FLOW= 1.85753
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Table 14. (continued)

```
NUMBER OF STAGES= 7                  RPM= 24000
INITIAL WEIGHT FLOW= 1.818

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984      V1= 2.774       Q1= 1
NS= 25.9954     DS= 2.47252     CO= 1430.79     H/D= 3.37649 E-2
C1= 500         C2= 1324.19     C3= 284.663     M2= .742438
A1= 90.         A2= 15          A3= 90
B2= 26.1281     W2= 778.249     W3= 646.399     MR2= .436344
UM= 580.347     UTIP= 600.261   DIA.= 5.73207   H= .193543
T3= 2460        HT3= 9.39034    S3= 7.93106     V3= 3.66096     Q3= .98435
STAGE EFF.= .739746             ETT= .752651    ETS= .722859

STAGE NO.-- 2
T1= 2460        HT1= 9.39034    S1= 7.93106     V1= 3.66096     Q1= .98435
NS= 32.0835     DS= 2.06591     CO= 1376.13     H/D= 4.74215 E-2
C1= 284.663     C2= 1273.63     C3= 283.229     M2= .737696
A1= 90.         A2= 15.0313     A3= 90
B2= 26.5096     W2= 740.028     W3= 634.544     MR2= .428629
UM= 567.833     UTIP= 595.364   DIA.= 5.6853    H= .269606
T3= 2340        HT3= 9.1838     S3= 7.96322     V3= 4.96156     Q3= .958015
STAGE EFF.= .732952             ETT= .768629    ETS= .73607

STAGE NO.-- 3
T1= 2340        HT1= 9.1838     S1= 7.96322     V1= 4.96156     Q1= .958015
NS= 37.3651     DS= 1.79776     CO= 1388.7      H/D= 5.54309 E-2
C1= 283.229     C2= 1286.88     C3= 325.642     M2= .771186
A1= 90.         A2= 16.75       A3= 90
B2= 29.4763     W2= 753.728     W3= 661.787     MR2= .451675
UM= 576.127     UTIP= 608.889   DIA.= 5.81446   H= .322301
T3= 2223        HT3= 8.9801     S3= 7.99897     V3= 6.91576     Q3= .931753
STAGE EFF.= .719315             ETT= .777859    ETS= .735087

STAGE NO.-- 4
T1= 2223        HT1= 8.9801     S1= 7.99897     V1= 6.91576     Q1= .931753
NS= 43.8354     DS= 1.55057     CO= 1409.38     H/D= 6.54605 E-2
C1= 325.642     C2= 1308.       C3= 380.232     M2= .811917
A1= 90.         A2= 18.875      A3= 90
B2= 32.9879     W2= 777.176     W3= 698.36      MR2= .482418
UM= 585.78      UTIP= 625.279   DIA.= 5.97097   H= .390863
T3= 2109        HT3= 8.77825    S3= 8.03895     V3= 9.94975     Q3= .905827
STAGE EFF.= .70533              ETT= .786374    ETS= .729138

STAGE NO.-- 5
T1= 2109        HT1= 8.77825    S1= 8.03895     V1= 9.94975     Q1= .905827
NS= 52.5231     DS= 1.31657     CO= 1423.55     H/D= 8.26367 E-2
C1= 380.232     C2= 1322.86     C3= 429.882     M2= .850732
A1= 90.         A2= 20.75       A3= 90
B2= 35.9936     W2= 797.481     W3= 731.469     MR2= .512861
UM= 591.823     UTIP= 642.533   DIA.= 6.13574   H= .507037
T3= 2000        HT3= 8.58025    S3= 8.08303     V3= 14.7195     Q3= .88092
STAGE EFF.= .691923             ETT= .794449    ETS= .722003

STAGE NO.-- 6
T1= 2000        HT1= 8.58025    S1= 8.08303     V1= 14.7195     Q1= .88092
NS= 63.124      DS= 1.12143     CO= 1455.07     H/D= .107754
C1= 429.882     C2= 1353.52     C3= 477.531     M2= .902953
A1= 90.         A2= 22.25       A3= 90
B2= 38.3193     W2= 826.57      W3= 770.155     MR2= .551415
UM= 604.242     UTIP= 672.33    DIA.= 6.42027   H= .691808
T3= 1893        HT3= 8.38127    S3= 8.13299     V3= 22.705      Q3= .85665
STAGE EFF.= .677813             ETT= .80099     ETS= .71472

STAGE NO.-- 7
T1= 1893        HT1= 8.38127    S1= 8.13299     V1= 22.705      Q1= .85665
NS= 78.2116     DS= .940099     CO= 1475.97     H/D= .14992
C1= 477.531     C2= 1374.22     C3= 519.982     M2= .951646
A1= 90.         A2= 23.625      A3= 90
B2= 40.3781     W2= 850.093     W3= 802.652     MR2= .58869
UM= 611.453     UTIP= 708.358   DIA.= 6.76431   H= 1.01411
T3= 1790        HT3= 8.1843     S3= 8.18858     V3= 36.3792     Q3= .83361
STAGE EFF.= .664366             ETT= .806742    ETS= .706614

TURBINE TOTAL ENTHALPY DROP= 1.43205      OVERALL CYCLE EFFICIENCY = .78396
OVERALL TURBINE EFFICIENCY= .733807

NEW WEIGHT FLOW= 1.81788
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Table 14. (continued)

```
NUMBER OF STAGES= 9                RPM= 24000
INITIAL WEIGHT FLOW= 1.792

STAGE NO.-- 1
T1= 2610        HT1= 9.61635   S1= 7.8934     V1= 2.774      Q1= 1
NS= 29.3702     DS= 2.22814    CO= 1283.66    H/D= 4.10788 E-2
C1= 500         C2= 1188.02    C3= 260.463    M2= .661585
A1= 90.         A2= 15         A3= 90
B2= 26.3319     W2= 693.199    W3= 587.194    MR2= .386028
UM= 526.271     UTIP= 548.312  DIA.= 5.23599  H= .215088
T3= 2488        HT3= 9.43127   S3= 7.92247    V3= 3.42371    Q3= .989679
STAGE EFF.= .75384             ETT= .762512   ETS= .731118

STAGE NO.-- 2
T1= 2488        HT1= 9.43127   S1= 7.92247    V1= 3.42371    Q1= .989679
NS= 35.692      DS= 1.87183    CO= 1217.53    H/D= .032013
C1= 260.463     C2= 1128.05    C3= 279.646    M2= .64831
A1= 90.         A2= 16.5       A3= 90
B2= 29.0199     W2= 660.427    W3= 576.453    MR2= .377217
UM= 504.084     UTIP= 530.943  DIA.= 5.07013  H= .263713
T3= 2393        HT3= 9.26803   S3= 7.94543    V3= 4.31434    Q3= .968435
STAGE EFF.= .748209            ETT= .77519    ETS= .734295

STAGE NO.-- 3
T1= 2393        HT1= 9.26803   S1= 7.94543    V1= 4.31434    Q1= .968435
NS= 39.814      DS= 1.69114    CO= 1229.23    H/D= 5.78794 E-2
C1= 279.646     C2= 1140.12    C3= 312.769    M2= .668583
A1= 90.         A2= 18         A3= 90
B2= 31.5237     W2= 673.827    W3= 598.196    MR2= .395147
UM= 509.921     UTIP= 540.229  DIA.= 5.15881  H= .298589
T3= 2300        HT3= 9.10635   S3= 7.9706     V3= 5.52466    Q3= .947424
STAGE EFF.= .736297            ETT= .781391   ETS= .730803

STAGE NO.-- 4
T1= 2300        HT1= 9.10635   S1= 7.9706     V1= 5.52466    Q1= .947424
NS= 44.916      DS= 1.51299    CO= 1237.75    H/D= 6.63794 E-2
C1= 312.769     C2= 1149.21    C3= 346.205    M2= .692173
A1= 90.         A2= 19.5       A3= 90
B2= 33.9683     W2= 686.578    W3= 619.622    MR2= .413527
UM= 513.886     UTIP= 549.036  DIA.= 5.24291  H= .348021
T3= 2210        HT3= 8.94732   S3= 7.99793    V3= 7.17851    Q3= .926885
STAGE EFF.= .724753            ETT= .787555   ETS= .725941

STAGE NO.-- 5
T1= 2210        HT1= 8.94732   S1= 7.99793    V1= 7.17851    Q1= .926885
NS= 50.6826     DS= 1.35961    CO= 1253.9     H/D= 7.88424 E-2
C1= 346.205     C2= 1164.91    C3= 370.612    M2= .719797
A1= 90.         A2= 20.375     A3= 90
B2= 35.4044     W2= 700.066    W3= 639.707    MR2= .432569
UM= 521.419     UTIP= 563.985  DIA.= 5.38566  H= .424618
T3= 2122        HT3= 8.78843   S3= 8.02812    V3= 9.50262    Q3= .90672
STAGE EFF.= .712641            ETT= .792987   ETS= .723712

STAGE NO.-- 6
T1= 2122        HT1= 8.78843   S1= 8.02812    V1= 9.50262    Q1= .90672
NS= 57.9702     DS= 1.20663    CO= 1267.32    H/D= 9.49409 E-2
C1= 370.612     C2= 1178.38    C3= 401.963    M2= .749836
A1= 90.         A2= 21.625     A3= 90
B2= 37.3572     W2= 715.69     W3= 662.449    MR2= .455413
UM= 526.563     UTIP= 578.624  DIA.= 5.52545  H= .524591
T3= 2036        HT3= 8.6311    S3= 8.06109    V3= 12.8353    Q3= .886945
STAGE EFF.= .700924            ETT= .798162   ETS= .717867

STAGE NO.-- 7
T1= 2036        HT1= 8.6311    S1= 8.06109    V1= 12.8353    Q1= .886945
NS= 66.7987     DS= 1.06812    CO= 1283.8     H/D= .116973
C1= 401.963     C2= 1194.6     C3= 432.293    M2= .781888
A1= 90.         A2= 22.75      A3= 90
B2= 39.0675     W2= 733.004    W3= 685.923    MR2= .479764
UM= 532.556     UTIP= 597.88   DIA.= 5.70933  H= .667839
T3= 1952        HT3= 8.4746    S3= 8.09724    V3= 17.7158    Q3= .867725
STAGE EFF.= .689244            ETT= .802695   ETS= .71168

STAGE NO.-- 8
T1= 1952        HT1= 8.4746    S1= 8.09724    V1= 17.7158    Q1= .867725
NS= 77.9343     DS= .942564    CO= 1299.91    H/D= .148993
C1= 432.293     C2= 1210.29    C3= 457.9      M2= .815169
A1= 90.         A2= 23.625     A3= 90
B2= 40.3764     W2= 748.714    W3= 706.844    MR2= .504282
UM= 538.481     UTIP= 623.277  DIA.= 5.95186  H= .886784
T3= 1870        HT3= 8.31876   S3= 8.13688    V3= 25.0338    Q3= .849192
STAGE EFF.= .677633            ETT= .806662   ETS= .706568

STAGE NO.-- 9
T1= 1870        HT1= 8.31876   S1= 8.13688    V1= 25.0338    Q1= .849192
NS= 92.1248     DS= .830739    CO= 1315.82    H/D= .195489
C1= 457.9       C2= 1225.71    C3= 481.052    M2= .850028
A1= 90.         A2= 24.375     A3= 90
B2= 41.4757     W2= 763.788    W3= 726.333    MR2= .529686
UM= 544.197     UTIP= 657.306  DIA.= 6.[illegible]2768  H= 1.22705
T3= 1790        HT3= 8.16351   S3= 8.18[illegible]35    V3= 36.2807    Q3= .831351
STAGE EFF.= .66614             ETT= .810028   ETS= .701762

TURBINE TOTAL ENTHALPY DROP= 1.45284      OVERALL CYCLE EFFICIENCY = .79080
OVERALL TURBINE EFFICIENCY= .742158

NEW WEIGHT FLOW= 1.79187
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Table 14. (continued)

```
NUMBER OF STAGES= 3              RPM= 24000
INITIAL WEIGHT FLOW= 1.671

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984       V1= 2.774       Q1= 1
NS= 16.3553     DS= 3.62767     CO= 2286.02      H/D= 1.72741 E-2
C1= 500         C2= 2115.71     C3= 406.045      M2= 1.25024
A1= 90.         A2= 15          A3= 90           C/H= 3.14758
B2= 25.0156     W2= 1294.94     W3= 960.229      MR2= .765219
UM= 870.155     UTIP= 885.314   DIA.= 8.45412    H= .146037
T3= 2251        HT3= 9.09769    S3= 8.01581      V3= 6.43065     Q3= .947829
STAGE EFF.= .659579             ETT= .698072     ETS= .676048

STAGE NO.-- 2
T1= 2251        HT1= 9.09769    S1= 8.01581      V1= 6.43065     Q1= .947829
NS= 27.3429     DS= 2.36837     CO= 2311.36      H/D= 3.65922 E-2
C1= 406.045     C2= 2139.16     C3= 463.82       M2= 1.38904
A1= 90.         A2= 15          A3= 90           C/H= 1.47102
B2= 26.2167     W2= 1253.27     W3= 1049.92      MR2= .813801
UM= 941.922     UTIP= 976.994   DIA.= 9.3296     H= .341391
T3= 1945        HT3= 8.57221    S3= 8.15524      V3= 18.5776     Q3= .882972
STAGE EFF.= .659643             ETT= .756941     ETS= .72646

STAGE NO.-- 3
T1= 1945        HT1= 8.57221    S1= 8.15524      V1= 18.5776     Q1= .882972
NS= 51.7487     DS= 1.3304      CO= 2390.37      H/D= .079753
C1= 463.82      C2= 2221.68     C3= 730.178      M2= 1.6031
A1= 90.         A2= 21          A3= 90           C/H= .605931
B2= 36.3496     W2= 1343.28     W3= 1231.92      MR2= .969271
UM= 992.218     UTIP= 1074.18   DIA.= 10.2577    H= .818081
T3= 1660        HT3= 8.0577     S3= 8.33023      V3= 73.6024     Q3= .819778
STAGE EFF.= .639105             ETT= .793849     ETS= .719775

TURBINE TOTAL ENTHALPY DROP= 1.55865       OVERALL CYCLE EFFICIENCY = .74962
OVERALL TURBINE EFFICIENCY= .684975

NEW WEIGHT FLOW= 1.67023
NUMBER OF STAGES= 5              RPM= 24000
INITIAL WEIGHT FLOW= 1.59

STAGE NO.-- 1
T1= 2610        HT1= 9.61635    S1= 7.8984       V1= 2.774       Q1= 1
NS= 19.0558     DS= 3.2067      CO= 1798.76      H/D= 2.12222 E-2
C1= 500         C2= 1664.75     C3= 334.165      M2= .951533
A1= 90.         A2= 15          A3= 90           C/H= 2.55301
B2= 25.4433     W2= 1002.91     W3= 777.821      MR2= .373241
UM= 702.384     UTIP= 717.445   DIA.= 6.85109    H= .145396
T3= 2381        HT3= 9.27838    S3= 7.95955      V3= 4.46941     Q3= .970255
STAGE EFF.= .696277             ETT= .719227     ETS= .694405

STAGE NO.-- 2
T1= 2381        HT1= 9.27838    S1= 7.95955      V1= 4.46941     Q1= .970255
NS= 25.5838     DS= 2.50628     CO= 1775.13      H/D= 3.29264 E-2
C1= 334.165     C2= 1642.88     C3= 352.166      M2= .991853
A1= 90.         A2= 15          A3= 90           C/H= 1.63644
B2= 26.0988     W2= 966.555     W3= 800.518      MR2= .583537
UM= 718.898     UTIP= 742.944   DIA.= 7.09459    H= .233599
T3= 2188        HT3= 8.95241    S3= 8.02554      V3= 7.74279     Q3= .929222
STAGE EFF.= .693026             ETT= .751233     ETS= .721666

STAGE NO.-- 3
T1= 2188        HT1= 8.95241    S1= 8.02554      V1= 7.74279     Q1= .929222
NS= 34.3329     DS= 1.94005     CO= 1802.91      H/D= 5.01213 E-2
C1= 352.166     C2= 1669.8      C3= 399.245      M2= 1.06797
A1= 90.         A2= 16          A3= 90           C/H= 1.05532
B2= 28.168      W2= 975.004     W3= 845.746      MR2= .623592
UM= 745.588     UTIP= 783.839   DIA.= 7.48511    H= .375163
T3= 2004        HT3= 8.6268     S3= 8.10272      V3= 14.6089     Q3= .888672
STAGE EFF.= .677884             ETT= .772853     ETS= .734954

STAGE NO.-- 4
T1= 2004        HT1= 8.6268     S1= 8.10272      V1= 14.6089     Q1= .888672
NS= 48.1772     DS= 1.42309     CO= 1840.87      H/D= 7.3[illegible] E-2
C1= 399.245     C2= 1709.64     C3= 528.209      M2= 1.16[illegible]
A1= 90.         A2= 19.875      A3= 90           C/H= .66[illegible]7
B2= 34.6068     W2= 1023.39     W3= 930.037      MR2= .69[illegible]
UM= 765.491     UTIP= 823.81    DIA.= 7.8668     H= .579949
T3= 1828        HT3= 8.30744    S3= 8.19236      V3= 30.6217     Q3= .849181
STAGE EFF.= .660897             ETT= .7908       ETS= .725693

STAGE NO.-- 5
T1= 1828        HT1= 8.30744    S1= 8.19236      V1= 30.6217     Q1= .849181
NS= 70.8348     DS= 1.014       CO= 1900.91      H/D= .126571
C1= 528.209     C2= 1769.71     C3= 663.592      M2= 1.28355
A1= 90.         A2= 23.5        A3= 90           C/H= .362317
B2= 40.1543     W2= 1094.32     W3= 1029.07      MR2= .793695
UM= 786.533     UTIP= 891.202   DIA.= 8.51035    H= 1.07716
T3= 1660        HT3= 7.99011    S3= 8.2982       V3= 72.8871     Q3= .811809
STAGE EFF.= .643627             ETT= .804315     ETS= .706297

TURBINE TOTAL ENTHALPY DROP= 1.62623       OVERALL CYCLE EFFICIENCY = .76769
OVERALL TURBINE EFFICIENCY= .710175

NEW WEIGHT FLOW= 1.60082
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Table 14. (continued)

```
NUMBER OF STAGES= 7                     RPM= 24000
INITIAL WEIGHT FLOW= 1.563

STAGE NO.-- 1
T1= 2610         HT1= 9.61635    S1= 7.8984      V1= 2.774        Q1= 1
NS= 22.1587      DS= 2.82967     CO= 1543.69     H/D= 2.64075 E-2
C1= 500          C2= 1428.68     C3= 297.553     M2= .805368
A1= 90.          A2= 15          A3= 90          C/H= 2.04548
B2= 25.8068      W2= 849.381     W3= 683.491     MR2= .478809
UM= 615.328      UTIP= 631.786   DIA.= 6.0331    H= .15932
T3= 2436         HT3= 9.3591     S3= 7.94065     V3= 3.88579      Q3= .980589
STAGE EFF.= .721507              ETT= .737033    ETS= .70965

STAGE NO.-- 2
T1= 2436         HT1= 9.3591     S1= 7.94065     V1= 3.88579      Q1= .980589
NS= 28.0852      DS= 2.31487     CO= 1488.21     H/D= 3.82027 E-2
C1= 297.553      C2= 1377.34     C3= 299.925     M2= .806599
A1= 90.          A2= 15          A3= 90          C/H= 1.40846
B2= 26.2612      W2= 305.671     W3= 677.85      MR2= .471819
UM= 607.891      UTIP= 631.538   DIA.= 6.03074   H= .230391
T3= 2297         HT3= 9.12211    S3= 7.98121     V3= 5.59323      Q3= .95053
STAGE EFF.= .717796              ETT= .759095    ETS= .728264

STAGE NO.-- 3
T1= 2297         HT1= 9.12211    S1= 7.98121     V1= 5.59323      Q1= .95053
NS= 33.7964      DS= 1.97278     CO= 1505.3      H/D= 5.06448 E-2
C1= 299.925      C2= 1393.53     C3= 319.212     M2= .849388
A1= 90.          A2= 15.375      A3= 90          C/H= 1.0543
B2= 27.1372      W2= 810.03      W3= 699.836     MR2= .493732
UM= 622.798      UTIP= 655.091   DIA.= 6.25565   H= .316816
T3= 2162         HT3= 8.88535    S3= 8.02722     V3= 8.38143      Q3= .920606
STAGE EFF.= .704114              ETT= .771896    ETS= .737184

STAGE NO.-- 4
T1= 2162         HT1= 8.88535    S1= 8.02722     V1= 8.38143      Q1= .920606
NS= 41.3192      DS= 1.63381     CO= 1531.58     H/D= 6.01947 E-2
C1= 319.212      C2= 1421.03     C3= 402.455     M2= .903241
A1= 90.          A2= 18.[illegible]       A3= 90          C/H= .842121
B2= 32.3437      W2= 842.807     W3= 752.254     MR2= .535708
UM= 635.55       UTIP= 674.875   DIA.= 6.44458   H= .387929
T3= 2030         HT3= 8.65138    S3= 8.07912     V3= 13.1957      Q3= .890632
STAGE EFF.= .689[illegible]07             ETT= .783365    ETS= .729274

STAGE NO.-- 5
T1= 2030         HT1= 8.65138    S1= 8.07912     V1= 13.1957      Q1= .890632
NS= 51.5961      DS= 1.33366     CO= 1562.02     H/D= 7.93448 E-2
C1= 402.455      C2= 1451.78     C3= 477.047     M2= .963353
A1= 90.          A2= 21          A3= 90          C/H= .609069
B2= 36.347       W2= 877.839     W3= 804.905     MR2= .582503
UM= 648.309      UTIP= 701.582   DIA.= 6.69961   H= .53158
T3= 1903         HT3= 8.4193     S3= 8.1378      V3= 21.8277      Q3= .861825
STAGE EFF.= .675107              ETT= .793726    ETS= .719695

STAGE NO.-- 6
T1= 1903         HT1= 8.4193     S1= 8.1378      V1= 21.8277      Q1= .861825
NS= 65.7357      DS= 1.07929     CO= 1606.23     H/D= .1[illegible]227
C1= 477.047      C2= 1494.88     C3= 546.627     M2= 1.03758
A1= 90.          A2= 23          A3= 90          C/H= .410868
B2= 39.4106      W2= 920.016     W3= 860.999     MR2= .638574
UM= 665.225      UTIP= 743.834   DIA.= 7.10309   H= .801419
T3= 1779         HT3= 8.18527    S3= 8.20549     V3= 38.5245      Q3= .834017
STAGE EFF.= .660271              ETT= .802227    ETS= .709317

STAGE NO.-- 7
T1= 1779         HT1= 8.18527    S1= 8.20549     V1= 38.5245      Q1= .834017
NS= 87.5038      DS= .863        CO= 1639.16     H/D= .179831
C1= 546.627      C2= 1526.66     C3= 592.125     M2= 1.10997
A1= 90.          A2= 24.125      A3= 90          C/H= .251366
B2= 41.[illegible]151       W2= 948.927     W3= 900.468     MR2= .689926
UM= 678.407      UTIP= 807.961   DIA.= 7.71545   H= 1.38747
T3= 1660         HT3= 7.95108    S3= 8.28309     V3= 72.5495      Q3= .808048
STAGE EFF.= .645109              ETT= .809081    ETS= .703503

TURBINE TOTAL ENTHALPY DROP= 1.66526       OVERALL CYCLE EFFICIENCY = .77949
OVERALL TURBINE EFFICIENCY= .722668

NEW WEIGHT FLOW= 1.5633
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Table 14. (continued)

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NUMBER OF STAGES= 9                    RPM= 2400[illegible]
INITIAL WEIGHT FLOW= 1.54

STAGE NO.-- 1
T1= 2610          HT1= 9.61635    S1= 7.8984     V1= 2.774        Q1= 1
NS= 24.95         DS= 2.56023     CO= 1381.53    H/D= 3.16579 E-2
C1= 500           C2= 1278.61     C3= 272.82     M2= .71511
A1= 90.           A2= 15          A3= 90         C/H= 1.7027
B2= 26.0516       W2= 753.51      W3= 621.197    MR2= .42143
UM= 558.085       UTIP= 576.023   DIA.= 5.50061  H= .174138
T3= 2469          HT3= 9.40602    S3= 7.92946    V3= 3.58405      Q3= .986563
STAGE EFF.= .73794                ETT= .748941   ETS= .719735

STAGE NO.-- 2
T1= 2469          HT1= 9.40602    S1= 7.92946    V1= 3.58405      Q1= .986563
NS= 30.8237       DS= 2.13776     CO= 1315.11    H/D= .04438
C1= 272.82        C2= 1217.16     C3= 269.247    M2= .701157
A1= 90.           A2= 15.0313     A3= 90         C/H= 1.2104
B2= 26.454        W2= 708.595     W3= 604.396    MR2= .408193
UM= 541.11[illegible]       UTIP= 565.636   DIA.= 5.40142  H= .239715
T3= 2359          HT3= 9.21698    S3= 7.95847    V3= 4.71856      Q3= .96244
STAGE EFF.= .734192               ETT= .76595    ETS= .733845

STAGE NO.-- 3
T1= 2359          HT1= 9.21698    S1= 7.95847    V1= 4.71856      Q1= .96244
NS= 35.288        DS= 1.89521     CO= 1327.9     H/D= 5.24839 E-2
C1= 269.247       C2= 1229.87     C3= 294.998    M2= .730802
A1= 90.           A2= 16          A3= 90         C/H= 1.00748
B2= 28.2034       W2= 717.297     W3= 624.195    MR2= .426226
UM= 550.09        UTIP= 579.672   DIA.= 5.53545  H= .290522
T3= 2251          HT3= 9.02898    S3= 7.99066    V3= 6.36658      Q3= .938347
STAGE EFF.= .721765               ETT= .774516   ETS= .736292

STAGE NO.-- 4
T1= 2251          HT1= 9.02898    S1= 7.99066    V1= 6.36658      Q1= .938347
NS= 41.0935       DS= 1.64142     CO= 1335.01    H/D= 5.96338 E-2
C1= 294.998       C2= 1238.66     C3= 350.619    M2= .759651
A1= 90.           A2= 18.5        A3= 90         C/H= .850101
B2= 32.3373       W2= 734.771     W3= 655.481    MR2= .450625
UM= 553.83        UTIP= 587.77    DIA.= 5.61279  H= .334712
T3= 2147          HT3= 8.84595    S3= 8.0255     V3= 8.7731       Q3= .914672
STAGE EFF.= .709881               ETT= .783073   ETS= .72906

STAGE NO.-- 5
T1= 2147          HT1= 8.84595    S1= 8.0255     V1= 8.7731       Q1= .914672
NS= 47.5249       DS= 1.4406      CO= 1361.82    H/D= 7.23865 E-2
C1= 350.619       C2= 1264.63     C3= 387.781    M2= .801194
A1= 90.           A2= 19.75       A3= 90         C/H= .683883
B2= 34.4048       W2= 756.304     W3= 686.293    MR2= .479148
UM= 566.241       UTIP= 608.578   DIA.= 5.81149  H= .420673
T3= 2045          HT3= 8.66147    S3= 8.06477    V3= 12.4554      Q3= .891438
STAGE EFF.= .696697               ETT= .79019    ETS= .726119

STAGE NO.-- 6
T1= 2045          HT1= 8.66147    S1= 8.06477    V1= 12.4554      Q1= .891438
NS= 56.0457       DS= 1.24256     CO= 1386.39    H/D= 9.03399 E-2
C1= 387.781       C2= 1288.88     C3= 433.585    M2= .844307
A1= 90.           A2= 21.375      A3= 90         C/H= .530651
B2= 36.9668       W2= 781.166     W3= 721.014    MR2= .51172
UM= 576.082       UTIP= 630.194   DIA.= 6.01791  H= .543657
T3= 1945          HT3= 8.47718    S3= 8.10855    V3= 18.2765      Q3= .868642
STAGE EFF.= .683951               ETT= .796947   ETS= .718999

STAGE NO.-- 7
T1= 1945          HT1= 8.47718    S1= 8.10855    V1= 18.2765      Q1= .868642
NS= 67.462        DS= 1.05993     CO= 1407.49    H/D= .119009
C1= 433.585       C2= 1309.7      C3= 474.151    M2= .887728
A1= 90.           A2= 22.75       A3= 90         C/H= .391402
B2= 39.0734       W2= 803.525     W3= 752.242    MR2= .544638
UM= 583.998       UTIP= 656.921   DIA.= 6.27313  H= .746559
T3= 1848          HT3= 8.29394    S3= 8.15706    V3= 27.708       Q3= .846758
STAGE EFF.= .671489               ETT= .802975   ETS= .711849

STAGE NO.-- 8
T1= 1848          HT1= 8.29394    S1= 8.15706    V1= 27.708       Q1= .846758
NS= 82.3217       DS= .903479     CO= 1435.24    H/D= .162758
C1= 474.151       C2= 1336.51     C3= 512.004    M2= .938433
A1= 90.           A2= 23.875      A3= 90         C/H= .279286
B2= 40.7467       W2= 828.757     W3= 784.419    MR2= .581912
UM= 594.281       UTIP= 696.765   DIA.= 6.65361  H= 1.08293
T3= 1753          HT3= 8.10991    S3= 8.21143    V3= 43.7474      Q3= .825646
STAGE EFF.= .6588                 ETT= .80786    ETS= .705051

STAGE NO.-- 9
T1= 1753          HT1= 8.10991    S1= 8.21143    V1= 43.7474      Q1= .825646
NS= 102.912       DS= .769145     CO= 1462.32    H/D= .235704
C1= 512.004       C2= 1362.51     C3= 544.474    M2= .992336
A1= 90.           A2= [illegible]4.75     A3= 90         C/H= .189112
B2= 42.02         W2= [illegible]52.16    W3= 813.387    MR2= .62064
UM= 604.277       UTIP= 755.52    DIA.= 7.21468  H= 1.70053
T3= 1660          HT3= 7.92501    S3= 8.27245    V3= 72.3119      Q3= .805401
STAGE EFF.= .646[illegible]45             ETT= .811828   ETS= .699281

TURBINE TOTAL ENTHALPY DROP= 1.69134          OVERALL CYCLE EFFICIENCY = .78692
OVERALL TURBINE EFFICIENCY= .731464

NEW WEIGHT FLOW= 1.5392
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Table 14. (continued)

```
NUMBER OF STAGES= 3                    RPM= 24000
INITIAL WEIGHT FLOW= 1.851

STAGE NO.-- 1
T1= 2460         HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 21.5112      DS= 2.90074     CO= 2176.05     H/D= 2.52686 E-2
C1= 500          C2= 2015.77     C3= 417.029     M2= 1.21491
A1= 90.          A2= 15          A3= 90          C/H= 2.13808
B2= 25.74        W2= 1201.32     W3= 960.249     MR2= .724037
UM= 864.971      UTIP= 887.094   DIA.= 8.47114   H= .214054
T3= 2158         HT3= 9.01867    S3= 8.08863     V3= 8.68551     Q3= .940976
STAGE EFF.= .686867              ETT= .733778    ETS= .706872

STAGE NO.-- 2
T1= 2158         HT1= 9.01867    S1= 8.08863     V1= 8.68551     Q1= .940976
NS= 34.7397      DS= 1.92324     CO= 2177.76     H/D= 5.18677 E-2
C1= 417.029      C2= 2016.61     C3= 475.071     M2= 1.32251
A1= 90.          A2= 15.75       A3= 90          C/H= 1.02346
B2= 27.7801      W2= 1174.45     W3= 1019.29     MR2= .779216
UM= 901.812      UTIP= 949.726   DIA.= 9.06921   H= .470399
T3= 1900         HT3= 8.54655    S3= 8.20954     V3= 22.6437     Q3= .882015
STAGE EFF.= .67269               ETT= .773574    ETS= .734761

STAGE NO.-- 3
T1= 1900         HT1= 8.54655    S1= 8.20954     V1= 22.6437     Q1= .882015
NS= 60.7023      DS= 1.15459     CO= 2229.06     H/D= 9.97908 E-2
C1= 475.071      C2= 2073.84     C3= 738.603     M2= 1.49073
A1= 90.          A2= 22.5        A3= 90          C/H= .469569
B2= 35.6497      W2= 1270.7      W3= 1182.6      MR2= .913411
UM= 923.592      UTIP= 1019.73   DIA.= 9.73769   H= .971732
T3= 1660         HT3= 8.09943    S3= 8.35421     V3= 74.1381     Q3= .825747
STAGE EFF.= .650584              ETT= .799732    ETS= .711926

TURBINE TOTAL ENTHALPY DROP= 1.40701        OVERALL CYCLE EFFICIENCY = .76903
OVERALL TURBINE EFFICIENCY= .686727

NEW WEIGHT FLOW= 1.85023

NUMBER OF STAGES= 5                    R.M= 24000
INITIAL WEIGHT FLOW= 1.778

STAGE NO.-- 1
T1= 2460         HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 25.4921      DS= 2.51394     CO= 1716.49     H/D= 3.27411 E-2
C1= 500          C2= 1588.6      C3= 340.307     M2= .927938
A1= 90.          A2= 15          A3= 90          C/H= 1.6458
B2= 26.0921      W2= 934.846     W3= 773.753     MR2= .546064
UM= 694.901      UTIP= 718.012   DIA.= 6.8565    H= .22449
T3= 2267         HT3= 9.18946    S3= 8.04179     V3= 6.21547     Q3= .96336
STAGE EFF.= .720796              ETT= .75091     ETS= .721394

STAGE NO.-- 2
T1= 2267         HT1= 9.18946    S1= 8.04179     V1= 6.21547     Q1= .96336
NS= 33.9318      DS= 1.96607     CO= 1679.32     H/D= 5.09852 E-2
C1= 340.307      C2= 1554.63     C3= 356.285     M2= .954623
A1= 90.          A2= 15.375      A3= 90          C/H= 1.04722
B2= 27.1423      W2= 903.518     W3= 780.976     MR2= .554806
UM= 694.975      UTIP= 731.258   DIA.= 6.98299   H= .35603
T3= 2105         HT3= 8.89305    S3= 8.09978     V3= 10.3123     Q3= .925237
STAGE EFF.= .708283              ETT= .77214     ETS= .737384

STAGE NO.-- 3
T1= 2105         HT1= 8.89305    S1= 8.09978     V1= 10.3123     Q1= .925237
NS= 44.429       DS= 1.53188     CO= 1698.32     H/D= .066611
C1= 356.285      C2= 1576.29     C3= 461.89      M2= 1.01938
A1= 90.          A2= 19          A3= 90          C/H= .753767
B2= 33.1942      W2= 937.369     W3= 843.666     MR2= .60619
UM= 706.003      UTIP= 754.468   DIA.= 7.20464   H= .479908
T3= 1950         HT3= 8.60641    S3= 8.16561     V3= 18.2865     Q3= .888051
STAGE EFF.= .690658              ETT= .787032    ETS= .728817

STAGE NO.-- 4
T1= 1950         HT1= 8.60641    S1= 8.16561     V1= 18.2865     Q1= .888051
NS= 59.2666      DS= 1.18295     CO= 1743.13     H/D= 9.77939 E-2
C1= 461.89       C2= 1621.07     C3= 560.217     M2= 1.1063
A1= 90.          A2= 21.875      A3= 90          C/H= .485208
B2= 37.7359      W2= 986.86      W3= 915.35      MR2= .673487
UM= 723.9        UTIP= 797.694   DIA.= 7.61742   H= .744937
T3= 1801         HT3= 8.32174    S3= 8.24261     V3= 35.1842     Q3= .852743
STAGE EFF.= .672386              ETT= .798932    ETS= .716411

STAGE NO.-- 5
T1= 1801         HT1= 8.32174    S1= 8.24261     V1= 35.1842     Q1= .852743
NS= 83.0796      DS= .892086     CO= 1780.04     H/D= .162491
C1= 560.217      C2= 1658.27     C3= 652.31      M2= 1.19638
A1= 90.          A2= 24.5        A3= 90          C/H= .276181
B2= 41.6056      W2= 1035.65     W3= 982.394     MR2= .747186
UM= 734.572      UTIP= 861.036   DIA.= 8.22228   H= 1.33605
T3= 1660         HT3= 8.04253    S3= 8.33117     V3= 73.6234     Q3= .[illegible]0012
STAGE EFF.= .655077              ETT= .808049    ETS= .699535

TURBINE TOTAL ENTHALPY DROP= 1.46392        OVERALL CYCLE EFFICIENCY = .78341
OVERALL TURBINE EFFICIENCY= .708054

NEW WEIGHT FLOW= 1.77831
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Table 14. (continued)

```
NUMBER OF STAGES= 7                    RPM= 24000
INITIAL WEIGHT FLOW= 1.739

STAGE NO.-- 1
T1= 2460        HT1= 9.50645    S1= 7.96755     V1= 3.7187      Q1= 1
NS= 29.6156     DS= 2.21236     CO= 1475.11     H/D= 4.16408 E-2
C1= 500         C2= 1365.81     C3= 299.673     M2= .786805
A1= 90.         A2= 15          A3= 90          C/H= 1.29124
B2= 26.3446     W2= 796.23      W3= 675.287     MR2= .458887
UM= 605.157     UTIP= 630.856   DIA.= 6.02423   H= .250854
T3= 2314        HT3= 9.26624    S3= 8.02546     V3= 5.44361     Q3= .973695
STAGE EFF.= .748996             ETT= .763123    ETS= .731629

STAGE NO.-- 2
T1= 2314        HT1= 9.26624    S1= 8.02546     V1= 5.44361     Q1= .973695
NS= 37.427      DS= 1.79523     CO= 1413.14     H/D= 5.55865 E-2
C1= 299.673     C2= 1309.52     C3= 331.431     M2= .781925
A1= 90.         A2= 16.75       A3= 90          C/H= .939662
B2= 29.4783     W2= 766.924     W3= 673.51      MR2= .457936
UM= 586.321     UTIP= 619.758   DIA.= 5.91825   H= .328975
T3= 2197        HT3= 9.05185    S3= 8.06135     V3= 7.64065     Q3= .945431
STAGE EFF.= .731134             ETT= .777953    ETS= .73516

STAGE NO.-- 3
T1= 2197        HT1= 9.05185    S1= 8.06135     V1= 7.64065     Q1= .945431
NS= 44.0329     DS= 1.54471     CO= 1437.3      H/D= .065968
C1= 331.431     C2= 1333.91     C3= 387.916     M2= .826316
A1= 90.         A2= 18.875      A3= 90          C/H= .76286
B2= 32.9927     W2= 792.469     W3= 712.381     MR2= .49891
UM= 597.507     UTIP= 638.118   DIA.= 6.09357   H= .401981
T3= 2082        HT3= 8.8389     S3= 8.10201     V3= 11.1319     Q3= .917439
STAGE EFF.= .715517             ETT= .786594    ETS= .729297

STAGE NO.-- 4
T1= 2082        HT1= 8.8389     S1= 8.10201     V1= 11.1319     Q1= .917439
NS= 52.8982     DS= 1.30768     CO= 1458.09     H/D= 8.32586 E-2
C1= 387.916     C2= 1355.88     C3= 443.289     M2= .871343
A1= 90.         A2= 20.875      A3= 90          C/H= .581647
B2= 36.1846     W2= 817.857     W3= 758.84      MR2= .5259
UM= 606.022     UTIP= 658.351   DIA.= 6.28679   H= .523429
T3= 1971        HT3= 8.62888    S3= 8.14756     V3= 16.773      Q3= .890487
STAGE EFF.= .708491             ETT= .794735    ETS= .72108

STAGE NO.-- 5
T1= 1971        HT1= 8.62888    S1= 8.14756     V1= 16.773      Q1= .890487
NS= 64.95       DS= 1.08955     CO= 1473.65     H/D= .110481
C1= 443.289     C2= 1371.49     C3= 501.228     M2= .915709
A1= 90.         A2= 23          A3= 90.         C/H= .419636
B2= 39.4031     W2= 844.213     W3= 789.618     MR2= .56366
UM= 618.14      UTIP= 680.692   DIA.= 6.50012   H= .718143
T3= 1865        HT3= 8.42405    S3= 8.19773     V3= 26.1044     Q3= .864957
STAGE EFF.= .686429             ETT= .801666    ETS= .709101

STAGE NO.-- 6
T1= 1865        HT1= 8.42405    S1= 8.19773     V1= 26.1044     Q1= .864957
NS= 79.7325     DS= .91467      CO= 1516.56     H/D= .149199
C1= 501.228     C2= 1413.28     C3= 566.653     M2= .981636
A1= 90.         A2= 25          A3= 90          C/H= .297621
B2= 42.2616     W2= 888.123     W3= 842.584     MR2= .616872
UM= 623.584     UTIP= 721.922   DIA.= 6.89304   H= 1.02856
T3= 1760        HT3= 8.21742    S3= 8.25504     V3= 42.877      Q3= .84003
STAGE EFF.= .671988             ETT= .807089    ETS= .694413

STAGE NO.-- 7
T1= 1760        HT1= 8.21742    S1= 8.25504     V1= 42.877      Q1= .84003
NS= 102.171     DS= .772702     CO= 1537.68     H/D= .202644
C1= 566.653     C2= 1432.72     C3= 572.443     M2= 1.03541
A1= 90.         A2= 24.75       A3= 90          C/H= .191607
B2= 42.0178     W2= 896.112     W3= 855.205     MR2= .647605
UM= 635.366     UTIP= 792.378   DIA.= 7.56665   H= 1.76034
T3= 1660        HT3= 8.00976    S3= 8.32058     V3= 73.3869     Q3= .817378
STAGE EFF.= .656163             ETT= .81172     ETS= .699223

TURBINE TOTAL ENTHALPY DROP= 1.49669      OVERALL CYCLE EFFICIENCY = .79187
OVERALL TURBINE EFFICIENCY= .718622

NEW WEIGHT FLOW= 1.73937
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Table 14. (continued)

```
NUMBER OF STAGES= 9                  RPM= 24000
INITIAL WEIGHT FLOW= 1.714

STAGE NO.-- 1
T1= 2460        HT1= 9.50645    S1= 7.96795     V1= 3.7187      Q1= 1
NS= 33.4024     DS= 1.9939      CO= 1322.1      H/D= 5.00389 E-2
C1= 500         C2= 1223.83     C3= 277.604     M2= .700005
A1= 90.         A2= 15.25       A3= 90          C/H= 1.06915
B2= 26.9189     W2= 711.032     W3= 613.121     MR2= .406696
UM= 546.744     UTIP= 574.746   DIA.= 5.48842   H= .274635
T3= 2341        HT3= 9.31074    S3= 8.01669     V3= 5.05841     Q3= .979669
STAGE EFF.= .753829             ETT= .771172    ETS= .737173

STAGE NO.-- 2
T1= 2341        HT1= 9.31074    S1= 8.01669     V1= 5.05841     Q1= .979669
NS= 41.1415     DS= 1.63912     CO= 1253.91     H/D= 5.98025 E-2
C1= 277.604     C2= 1163.41     C3= 329.371     M2= .684284
A1= 90.         A2= 18.5        A3= 90          C/H= .847686
B2= 32.3392     W2= 690.096     W3= 615.724     MR2= .405896
UM= 520.227     UTIP= 552.201   DIA.= 5.27313   H= .315346
T3= 2248        HT3= 9.14105    S3= 8.04239     V3= 6.55301     Q3= .956766
STAGE EFF.= .746071             ETT= .783161    ETS= .729125

STAGE NO.-- 3
T1= 2248        HT1= 9.14105    S1= 8.04239     V1= 6.55301     Q1= .956766
NS= 46.5317     DS= 1.46874     CO= 1266.4      H/D= 7.05496 E-2
C1= 329.371     C2= 1175.82     C3= 355.252     M2= .71128
A1= 90.         A2= 19.5        A3= 90          C/H= .705025
B2= 34.005      W2= 701.804     W3= 635.21      MR2= .424538
UM= 526.586     UTIP= 564.932   DIA.= 5.3947    H= .380594
T3= 2158        HT3= 8.97277    S3= 8.0708      V3= 8.62725     Q3= .934646
STAGE EFF.= .732938             ETT= .789224    ETS= .727119

STAGE NO.-- 4
T1= 2158        HT1= 8.97277    S1= 8.0708      V1= 8.62725     Q1= .934646
NS= 53.0515     DS= 1.30457     CO= 1280.39     H/D= 8.36786 E-2
C1= 355.252     C2= 1189.93     C3= 389.337     M2= .74069
A1= 90.         A2= 20.875      A3= 90          C/H= .578709
B2= 36.1871     W2= 716.139     W3= 659.418     MR2= .447018
UM= 532.216     UTIP= 578.411   DIA.= 5.52342   H= .462191
T3= 2070        HT3= 8.80633    S3= 8.10207     V3= 11.59       Q3= .912979
STAGE EFF.= .719948             ETT= .794849    ETS= .721355

STAGE NO.-- 5
T1= 2070        HT1= 8.80633    S1= 8.10207     V1= 11.59       Q1= .912979
NS= 60.9587     DS= 1.15069     CO= 1297.22     H/D= .100328
C1= 389.337     C2= 1206.89     C3= 429.931     M2= .773417
A1= 90.         A2= 22.5        A3= 90          C/H= .466106
B2= 38.6527     W2= 739.443     W3= 688.331     MR2= .473862
UM= 537.552     UTIP= 593.933   DIA.= 5.67164   H= .570159
T3= 1984        HT3= 8.6417     S3= 8.13641     V3= 15.9137     Q3= .891879
STAGE EFF.= .707311             ETT= .799873    ETS= .712012

WISTAGE NO.-- 6
T1= 1984        HT1= 8.6417     S1= 8.13641     V1= 15.9137     Q1= .891879
NS= 70.7266     DS= 1.01519     CO= 1316.19     H/D= .126232
C1= 429.931     C2= 1225.35     C3= 459.442     M2= .808728
A1= 90.         A2= 23.5        A3= 90          C/H= .36329
B2= 40.1534     W2= 757.719     W3= 712.492     MR2= .500094
UM= 544.577     UTIP= 616.848   DIA.= 5.89046   H= .74357
T3= 1900        HT3= 8.47751    S3= 8.1744      V3= 22.3758     Q3= .871569
STAGE EFF.= .69462              ETT= .804274    ETS= .706273

STAGE NO.-- 7
T1= 1900        HT1= 8.47751    S1= 8.1744      V1= 22.3758     Q1= .871569
NS= 83.3158     DS= .890184     CO= 1333.33     H/D= .163301
C1= 459.442     C2= 1242.12     C3= 488.653     M2= .844789
A1= 90.         A2= 24.5        A3= 90          C/H= .274727
B2= 41.6068     W2= 775.735     W3= 735.905     MR2= .527591
UM= 550.253     UTIP= 645.469   DIA.= 6.16377   H= 1.00655
T3= 1818        HT3= 8.31435    S3= 8.21618     V3= 32.2797     Q3= .852019
STAGE EFF.= .682329             ETT= .808109    ETS= .699567

STAGE NO.-- 8
T1= 1818        HT1= 8.31435    S1= 8.21618     V1= 32.2797     Q1= .852019
NS= 99.5332     DS= .786936     CO= 1350.67     H/D= .222723
C1= 488.653     C2= 1258.38     C3= 499.93      M2= .882411
A1= 90.         A2= 24.625      A3= 90          C/H= .200697
B2= 41.8409     W2= 786.039     W3= 749.446     MR2= .551191
UM= 558.34      UTIP= 690.539   DIA.= 6.59416   H= 1.46867
T3= 1738        HT3= 8.1506     S3= 8.26272     V3= 47.8905     Q3= .833439
STAGE EFF.= .669329             ETT= .811315    ETS= .700166

STAGE NO.-- 9
T1= 1738        HT1= 8.1506     S1= 8.26272     V1= 47.8905     Q1= .833439
NS= 121.684     DS= .692511     CO= 1360.99     H/D= .321439
C1= 499.93      C2= 1268.41     C3= 516.291     M2= .917682
A1= 90.         A2= 25.125      A3= 90          C/H= .137469
B2= 42.5688     W2= 796.123     W3= 763.206     MR2= .575989
UM= 562.078     UTIP= 748.593   DIA.= 7.14854   H= 2.29782
T3= 1660        HT3= 7.98867    S3= 8.3136      V3= 73.231      Q3= .815641
STAGE EFF.= .657206             ETT= .814106    ETS= .696951

TURBINE TOTAL ENTHALPY DROP= 1.51777        OVERALL CYCLE EFFICIENCY = .79734
OVERALL TURBINE EFFICIENCY= .725438

NEW WEIGHT FLOW= 1.71521
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Table 15. Effects of Number of Stages of Regenerative Feed Heating with a Turbine Inlet Temperature of 2150°F and a Condenser Temperature of 1330°F

Fluid	Number of Turbine Stages	Number of Stages of Regenerative Feed Heating	Turbine Efficiency η_t ~ %	Useful Enthalpy Drop in Turbine $\Sigma\ \eta_t \Delta his$	Enthalpy Rise in Boiler Δh_{boiler}	Cycle Efficiency η_c
Cs	1	0	100	62	220.25	28.15
		0	75	46.5	220.25	20.9
	2	0	75	47.4	220.25	21.5
		1	75	47.4	195.4	24.25
	3	0	75	47.7	220.25	21.65
		2		47.7	187	25.5
	5	0	75	47.8	220.25	21.7
		4		47.8	180	26.55
K	1	0	100	249.5	883.2	28.3
		0	75	187	883.2	20.4
	5	0	75	191.2	883.2	21.65
		4	75	191.2	752.1	25.4
	7	0	75	193.2	883.2	21.9
		6	75	193.2	743	26.0
	9	0	75	194.6	883.2	22.1
		8	75	194.6	738	26.4

Table 16. Effects of Ratio of h_l to h_{sv}

Fluid	Temperature (°F) T	Enthalpy of Liquid (~Btu/lb) h_l	Heat of Vaporization (~Btu/lb) Δh_v	Enthalpy Rise in Liquid from Condenser to Boiler (~Btu/lb) Δh_l	Ratio of Liquid Enthalpy Rise to Heat of Vaporization $\Delta h_l/h_v$
Cs	1400	103.81			
	2150	150.58	166.29	46.77	.281
K	1400	360.73			
	2150	510.18	714.7	149.45	.209

FOLDOUT FRAME

Table 17. Calculations Showing the Individual Effects of Aerod

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
	No Interstage Bleed				No Seal, Bleed or Moisture Losses		
Conditions	Fraction of Flow Through Stage	Net Stage Output	Turbine Output	η_c	Net Stage Output	Turbine Output	η_c
	$\left(1 - \frac{(40)}{4}\right) - \frac{(30)}{(25)}$	$(46)(a)\left(\frac{100 - (47)}{100}\right)$	$\Sigma (b)$	$\frac{(c)}{(44)_{\text{last stage}}}$	$(34) \times (41) = (45)$	$\Sigma (46)$ or $\Sigma (e)$	$\frac{(f)}{(44)_{\text{last stage}}}$
2150/1330	.99125	29.99			31.64		%
(5-Stage K)	.87144	30.98		%	39.07		
24,000 rpm	.90356	32.96			42.29		
	.91951	35.64			47.93		
	.92715	35.19	164.76	18.66	50.35	211.28	23.92
2150/1200	.98850	36.70			39.39		
(5-Stage K)	.85487	34.35			45.27		
24,000 rpm	.89401	35.49			47.54		
	.91679	40.09			56.51		
	.92375	40.03	186.66	20.54	61.04	249.75	27.49
2000/1300	.99675	26.61			27.14		
(5-Stage K)	.92559	29.58			33.86		
24,000 rpm	.93632	32.07			38.06		
	.94311	33.61			41.68		
	.94513	30.94	152.81	17.46	40.29	181.03	20.69
2000/1200	.99500	32.06			33.05		
(5-Stage K)	.91027	34.16			40.41		
	.92905	37.00			45.39		
	.93740	40.46			52.48		
	.94070	36.81	180.49	20.04	50.73	222.06	24.66
2150/1330	.99000	14.10			14.99		
(3-Stage Cs)	.92007	14.43			17.98		
18,000 rpm	.93218	14.72	43.25	19.64	20.05	53.02	24.07
2150/1200	.98700	16.47			17.85		
(3-Stage Cs)	.90935	16.03			20.89		
18,000 rpm	.92806	17.24	49.74	21.81	24.64	63.38	27.79
2000/1330	.99050	12.25			12.98		
(3-Stage Cs)	.94144	13.56			16.27		
18,000 rpm	.94492	12.37	38.18	17.58	16.04	45.29	20.86
2000/1200	.98775	14.86			16.03		
(3-Stage Cs)	.93089	14.94			18.66		
18,000 rpm	.93778	15.79	45.55	20.25	21.73	56.42	25.08

FOLDOUT FRAME 2

FOLDOUT FRAME

of Aerodynamic (Baljé), Interstage Bleed, Seal, and Moisture Churning Losses as Well as Regenerative Feed Heating

g	h	i	j	k	l	m	n	o	p
...ure Losses	No Seal or Bleed Losses				Balje Losses and Regenerative Feed Heating. No Seal or Moisture Losses			Balje + Moisture ... No Regenerative ...	
η_c	Net Stage Output	Turbine Output	η_c	Enthalpy Rise in Boiler	Net Stage Output	Turbine Output	η_c	In Flow Fraction	Net Stage Output
(f) / (44) last stage	(e) × (100 − (47))	Σ (h)	(i) / (44) last stage	(44) last stage	(46) × (20)	Σ (l)	(m) / (44)°		(a) × (46) × (100 − (47)) / 100
%	30.26				31.64			.9912	29.9
	35.55		%		37.3			.9217	32.8
	36.48				38.65			.935	34.1
	38.76				41.95			.939	36.4
23.92	37.95	179.00	20.27	883.17	42.00	191.54	25.45	.938	35.5
	37.12				39.4			.9885	36.7
	40.18				43.0			.896	36.0
	39.70				43.0			.919	36.4
	43.72				48.5			.930	40.6
27.49	43.34	204.06	22.46	908.60	49.8	223.7	29.7	.930	40.3
	36.70								
	31.96								
	34.25								
	35.64								
20.69	32.74	171.29	19.57	875.17					
	32.22								
	37.53								
	39.83								
	43.16								
24.66	39.13	191.87	21.30	900.60					
	14.24				14.99				
	15.69				16.50				
24.07	15.79	45.72	20.76	220.25	16.67	48.07	25.7		
	16.69				17.85				
	17.63				18.85				
27.79	18.57	52.89	23.19	228.10	20.00	56.7	29.8		
	12.36								
	14.40								
20.86	13.09	39.85	18.35	217.13					
	15.05								
	16.05								
25.08	16.84	47.94	21.31	224.98					

FOLDOUT FRAME 3

...Regenerative Feed Heating

n	o	p	q	r
...ve Feed ...e Losses	Balje + Moisture + Seal Losses No Regenerative Feed Heating			
η_c	In Flow Fraction	Net Stage Output	Turbine Output	η_c
m / 44°		$a \times \left(\frac{100 - 46 - 47}{100}\right)$	Σ p	q / K
	.9912	29.9		
	.9217	32.8		
	.935	34.1		
	.939	36.4		
25.45	.938	35.5	168.7	19.1
	.9885	36.7		
	.896	36.0		
	.919	36.4		
	.930	40.6		
29.7	.930	40.3	190.0	20.9
25.7				
29.8				

Table 18. Summary of Calculations of Individual Effects of Aerodynamic (Baljé), Seal Leakage and Moisture Losses and of Regenerative Feed Heating

Fluid	Number of Stages	T_o/T_c	Aerodynamic Losses (Baljé)	Regenerative Feed Heating	Seal Losses	Moisture Churning Losses	Enthalpy Drop in Turbine (Btu/lb) Δh_{ad}	Enthalpy Rise in Boiler (Btu/lb) Δh_b	Turbine Efficiency (%) η_t
Cs	3	2150/1330	No	No	No	No	62	220.25	27.9
			Yes	No	No	No	53.02	220.25	23.85
			Yes	Yes	No	No	48.07	186.91	25.7
			Yes	No	No	Yes	45.72	220.25	20.6
			Yes	Yes	Yes	Yes	39.46	186.91	21.11
			Yes	No	Yes	Yes	43.25	220.35	19.64
K	5	2150/1330	No	No	No	No	249.5	883.2	28.3
			Yes	No	No	No	207.5	883.2	23.55
			Yes	Yes	No	No	191.5	752	25.45
			Yes	No	No	Yes	179	883.2	20.3
			Yes	Yes	Yes	Yes	149.6	752	19.9
			Yes	No	Yes	Yes	168.7	883.2	19.12
Cs	3	2150/1200	No	No	No	No	74.3	228.1	32.55
			Yes	No	No	No	63.38	228.1	27.8
			Yes	Yes	No	No	56.7	190	29.85
			Yes	No	No	Yes	52.89	228.1	23.2
			Yes	Yes	Yes	Yes	44.74	190	23.55
			Yes	No	Yes	Yes	49.74	228.1	21.81
K	5	2150/1200	No	No	No	No	298.6	908.6	32.85
			Yes	No	No	No	249.75	908.6	27.5
			Yes	Yes	No	No	223.7	758.2	29.5
			Yes	No	No	Yes	204.1	908.6	22.46
			Yes	Yes	Yes	Yes	167.5	758.2	22.1
			Yes	No	Yes	Yes	190.0	908.6	20.9

Table 19. Reference Design Cases Chosen for Detailed Rotor and Bearing Dynamics Studies

Case No.	Figure No.	Fluid	Number of Turbine Stages	Number of Bearings	RPM	Moisture Deposition Analysis
1	20	Cs	3	4	18,000	Yes
2	22	Cs	2	2	18,000	Yes
3	24	Cs	3	2	18,000	No
4	26	K	5	4	24,000	Yes
5	28	K	8	4	24,000	Yes
6	30	K	3+2[a]	2	24,000	No

[a]Three stages at one end of the generator and two stages at the other end.

Table

	①		②	③		④	⑤	⑥	⑦	⑧
	Stage No.		Temperature (°F)		P (psia)	V3 (ft^3/lb)	S_{ad} (entropy)	Vapor Quality Isentropic (%)	Vapor Quality Assumed η_t (%)	h_{is} (enthalpy)
Cesium	0		2150		314.6	0.525	0.3205	100	100	320
	1		1740		114.5	1.3065	0.3238	89	93	291.4
	2		1330		23.6	5.5691	0.3286	79.1	83.1	264
Cesium	0		2150		314.6	0.525	0.3205	100	100	320
	1		1880		172.2	0.9001	0.3222	93.5	95.6	302
	2		1610		74.4	1.9375	0.3248	86.7	89.6	284.5
	3		1330		23.6	5.5691	0.3296	80.2	84.2	265.7
Potassium	0		2150		214.3	2.77	1.0149	100	100	1230.5
	1		1990		148.0	3.82	1.0190	96.7	98.1	1192.0
	2		1820		87.0	6.20	1.0255	92.6	94.3	1150.0
	3		1660		48.6	10.56	1.0325	88.8	90.6	1110.0
	4		1500		24.7	19.74	1.0410	85.2	87.3	1072.5
	5		1330		10.4	43.74	1.0545	80.9	83.7	1025.0
Potassium	0		2150	14.58	214.3	2.77	1.0149	100	100	1230.5
	1	2510	2050	11.93	175.3	3.28	1.017	98.4	99.2	1207.5
	2	2410	1950	8.95	131.5	4.26	1.020	96.2	97.1	1185.5
	3	2310	1850	6.54	96.1	5.66	1.0235	93.9	94.8	1162.0
	4	2210	1750	4.64	68.2	7.75	1.0272	91.6	92.7	1138.5
	5	2110	1650	3.18	46.7	10.96	1.0215	89.4	90.1	1113.2
	6	2010	1550	2.10	30.8	16.07	1.0335	86.6	87.8	1088.0
	7	1900	1440	1.26	18.5	25.76	1.0405	83.8	85.0	1057.5
	8	1790	1330	0.71	10.4	43.74	1.0465	80.7	82.0	1024.2

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e 20. Thermodynamic Calculations for Reference Designs

9	10	11	12	13	14	15	16	17	18	19
h_{ad}	Δh_{is}	η_t	Δh_{ad}	H_{ad}	C_o	T_ℓ	h_ℓ	Δh_ℓ	h_{vapor}	Vapor Bleed Fraction
$(9)_{n-1} - (12)_n$	$(9)_{n-1} - (8)_n$	(%)	(10)(11)	778(10)	$\sqrt{64.44\,(13)}$		(Btu/lb)	(Btu/lb)	(Btu/lb)	(%)
320										
298.6	28.6	0.75	21.45	22,251	1196.5	1652	124.62		187.46	
272.6	34.6		25.95	26,919	1316.0	1300	99.75	24.87	207.20	12.0
	63.2		47.4							
305.8	18.0	0.791	14.238	14,004	947.9	1814	133.09		180.81	
290.1	21.3	0.736	15.677	16,571	1033.0	1548	116.79	16.3	193.66	8.42
274.2	24.4	0.650	15.86	18,983	1105.7	1300	99.75	17.04	207.20	8.22
	63.7	0.726	45.775							
1230.5							510.57			
1201.0	38.5	0.766	29.491	29,953	1388.9	1948	478.39	32.18	738.38	4.35
1163.9	51.0	0.727	37.077	39,678	1598.5	1780	444.01	34.38	763.44	4.50
1125.8	53.9	0.706	38.053	41,934	1643.3	1620	412.44	31.57	787.45	4.01
1089.8	53.3	0.675	35.978	41, 467	1634.2	1460	381.05	31.39	812.35	3.86
1049.6	64.8	0.621	40.241	50,414	1801.8	1300	347.33	33.72	383.81	4.02
	261.5	0.699	180.84							
1230.5							510.57			
1213.25	23.0	0.75	17.25	17,894	1073.5	2025	489.46	21.11	729.78	2.89
1192.44	27.75		20.8125	21,590	1179.2	1925	469.36	20.10	744.37	2.70
1169.61	30.44		22.83	23,682	1235.0	1825	449.58	18.78	758.97	2.61
1146.28	31.11		23.3325	24,204	1248.5	1725	429.90	19.68	773.87	2.54
1121.47	33.08		24.81	25,736	1287.4	1624	410.21	19.69	789.14	2.50
1096.37	33.47		25.1025	26,040	1295.0	1522	390.44	19.77	804.70	2.46
1067.22	38.87		29.1525	30,241	1395.5	1412	370.63	19.81	820.33	2.51
1034.96	43.02		32.265	33,470	1468.2	1300	347.33	23.30	838.81	2.78

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(19)	(20)	(21)	(22)
Vapor Bleed Fraction (%)	Flow Fraction into Stage	Turbine Δh (Btu/lb)	(12) (20)
	1.00		21.45
12.0	0.88	47.4	22.84
			44.286
	1.00		14.238
8.42	0.916		14.360
8.22	0.834	45.76	13.227
			41.825
4.35	1.00		29.491
4.50	0.955		35.408
4.01	0.915		34.818
3.86	0.876		31.517
4.02	0.836	180.9	33.641
			164.875
2.89	1.00		17.25
2.70	0.971		20.21
2.61	0.944		21.55
2.54	0.918		21.42
2.50	0.893		22.16
2.46	0.868		21.79
2.51	0.843		24.58
2.78	0.819	195.54	26.42
			175.38

	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)
	Flow, W	N	Stage No.	P_3	No. Lands in Seal	Seal Leakage	V'_3	H_{ad}	N_s	η	D_s	$H_{ad}^{1/4}$	$V'_3{}^{1/2}$
	(lb/sec)	(rpm)		(psia)		(lb/sec)	(ft^3/sec)	(ft-lb/lb)		(%)			
							$\frac{(4)(7)}{100}(25)\left(1-\frac{(30)}{(25)}\right) \Big/ (28)$		$\frac{(26)\sqrt{(31)}}{(32)^{.75}}$			$(32)^{.25}$	$\sqrt{(31)}$
Cesium	7.9	18,000	1	114.5	12	-0-	9.5985	22,251	30.61	81.8	1.83	12.2134	3.0981
			2	23.6		0.33	30.8296	26,919	47.56	82.2	1.55	12.8090	5.5524
	6.6	18,000	1	172.2	12	-0-	5.6793	14,004	33.32	82.5	1.72	10.8783	2.3831
			2	74.4		0.43	9.8115	16,571	38.60	83.7	1.54	11.3459	3.1323
			3	23.6		0.20	25.0291	18,983	55.68	82.6	1.38	11.7379	5.0029
Potassium	1.6	24,000	1	148.0	12	-0-	5.9958	29,953	25.81	80.2	2.10	13.1556	2.4486
			2	87.0		0.178	7.9397	39,678	24.05	79.7	2.24	14.1136	2.8177
			3	48.6		0.111	13.0349	41,934	29.57	81.5	1.89	14.3101	3.6104
			4	24.7		0.068	23.1272	41,467	39.72	83.9	1.50	14.2701	4.8091
			5	10.4		0.038	47.8070	50,414	49.32	82.3	1.51	14.9843	6.9143
	2.16	24,000	1	175.3	12	-0-	7.0281	17,894	41.12	84.3	1.46	11.5658	2.6511
			2	131.5		0.158	8.4427	21,590	39.15	83.6	1.55	12.1217	2.9056
			3	96.1		0.121	10.3280	23,682	40.40	84.0	1.47	12.4052	3.2137
			4	68.2		0.096	13.6124	24,204	45.63	84.9	1.35	12.4730	3.6895
			5	46.7		0.072	18.4128	25,736	50.68	85.5	1.25	12.6659	4.2910
			6	30.8		0.055	25.7800	26,040	59.45	86.4	1.13	12.7031	5.0774
			7	18.5		0.037	39.1874	30.241	65.51	86.6	1.07	13.1871	6.2600
			8	10.4		0.023	62.7747	33,470	76.84	80.4	1.04	13.5258	7.9230

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Table 21. Aerodynamic Calculations for Reference Designs

	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)
/4	$V'_s{}^{1/2}$	Rotor Diam (ft)	Turbine Tip Speed (ft/sec)	Moisture Assumed, η	Δh_{is}	Net In-Flow Fraction	Δh_{boiler}	Δh_{boiler} (No Bleed)	h/D	$\eta\ \Delta h_{is}$	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	Σ (Net Stage Output)
	$\sqrt{(31)}$	$\frac{(35)(37)}{(36)}$	0.0523598 (26)(38)	1 - (7)	(10)	(20)	$(8)_o - (16)_1$	$(8)_o - (16)_n$		(34)(41)	1.25 (40)	$(42)\left(1-\frac{(40)}{4}\right)-(30)(25)$	$(46)(48)\left(\frac{100-(47)}{100}\right)$	Σ (49)
34	3.0981	0.563	467	0.07	28.6	1.00	195.38	195.38	0.0540	23.39	8.75	0.9825	20.97	38.94
90	5.5524	0.663	676	0.169	24.6	0.88		220.25	0.0664	28.44	21.125	0.8010	17.97	
83	2.3831	0.424	413	0.044	18.0	1.00	186.91	186.91	0.0590	14.85	5.500	0.9890	13.88	
59	3.1323	0.473	467	0.104	21.3	0.916		203.21	0.0689	17.83	13.000	0.8270	12.83	
79	5.0029	0.530	646	0.158	24.4	0.834		220.25	0.0784	20.15	19.750	0.7708	12.47	39.18
56	2.4486	0.444	581	0.019	38.5	1.00	752.11	752.11	0.0443	30.88	2.375	0.9952	30.00	
36	2.8177	0.505	664	0.057	51.0	0.955		786.49	0.0403	40.65	7.125	0.8301	31.34	
01	3.6104	0.533	709	0.094	53.9	0.915		818.06	0.0516	43.93	11.750	0.8241	31.95	
01	4.8091	0.558	752	0.127	53.3	0.876		849.45	0.0715	44.72	15.875	0.8057	30.31	
43	6.9143	0.620	1036	0.163	64.8	0.836		883.17	0.0690	53.33	20.375	0.7782	33.05	156.65
58	2.6511	0.423	420	0.008	23.0	1.00	74.104	741.04	0.0743	19.39	1.00	0.9980	19.16	
17	2.9056	0.459	467	0.029	27.75	0.971		761.14	0.0681	23.20	3.62	0.8908	19.92	
52	3.2137	0.485	479	0.052	30.44	0.944		780.92	0.0736	25.57	6.50	0.8757	20.94	
30	3.6895	0.501	502	0.073	31.11	0.918		800.60	0.0829	26.41	9.12	0.8568	20.56	
59	4.2910	0.529	532	0.099	33.08	0.893		820.29	0.0922	28.28	12.38	0.8376	20.75	
31	5.0774	0.557	568	0.122	33.47	0.868		840.06	0.1058	28.92	15.25	0.8161	20.00	
71	6.2600	0.620	638	0.150	38.87	0.843		859.87	0.1139	33.74	18.75	0.7943	21.77	
38	7.9230	0.642	766	0.180	43.02	0.819		883.17	0.1173	34.59	22.50	0.7715	20.68	16.378

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49	50	51	52	53	54	55	56	57
Net Stage Output	Σ (Net Stage Output)	η_c (%)	Power (kwe)	Rotor Diam (in.)	Blade Height (in.)	Weight Flow Correction	Corrected Rotor Diam	Corrected Blade Height
$(46)(48)\left(\frac{100-(47)}{100}\right)$	$\Sigma(49)$	$\frac{(50)}{(43)}$	$0.949311\,(25)(50)$	$12\,(38)$	$12\,(38)(45)$	$\sqrt{\frac{333}{(52)}}$	$(53)(55)$	$(54)(55)$
20.97	38.94	19.93	292.03	6.753	0.180	1.06837	7.215	0.193
17.97		(17.94)		7.951	0.461		8.495	0.493
13.88				5.085	0.216		5.923	0.251
12.83				5.682	0.308		6.618	0.359
12.47	39.18	20.96	245.48	6.359	0.702	1.16470	7.406	0.818
30.00				5.323	0.147		6.297	0.174
31.34				6.065	0.146		7.175	0.173
31.95				6.391	0.224		7.561	0.266
30.31				6.694	0.401		7.919	0.465
33.05	156.65	20.83	237.94	7.437	0.692	1.18301	8.798	0.819
19.16				5.076	0.238		5.076	0.238
19.92				5.503	0.227		5.503	0.227
20.94				5.818	0.264		5.818	0.264
20.56				6.014	0.337		6.014	0.337
20.75				6.353	0.422		6.353	0.422
20.00				6.684	0.572		6.684	0.572
21.77				7.442	0.736		7.442	0.736
20.68	16.378	22.10	335.83	7.699	1.150		7.699	1.150

Table 22-a.

	(70)	(71)	(72)	(73)	(74)	(75)	(76)
	Nozzle Pressure Ratio	Vapor Weight Flow Rate	Vapor Volume Flow Rate	Rotor OD	Rotor Diameter at Blade Root	Rotor Blade Height	Rotor Blade Width (Axial Pitchline Component)
	(P_1/P_2)	(lb/sec)	(ft^3/sec)	(in.)	(in.)		(in.)
	$\frac{(3)_{n-1}}{(3)_n}$	$(23)(48)\frac{333}{(52)}$	$(4)(71)[1-0.75(1-(7))]$			$\frac{(73)-(74)}{2}$	
Cs	2.75	7.39	9.148	7.215	6.83	0.193	0.25
	4.85	6.03	29.325	8.495	7.51	9.493	0.30
Cs	1.83	8.79	7.651	5.923	5.42	0.251	0.25
	2.31	7.35	13.130	6.618	5.90	0.359	0.25
	3.15	6.85	33.628	7.406	5.77	0.818	0.36
K	1.45	2.21	8.322	6.297	5.95	0.174	0.25
	1.70	1.84	10.920	7.175	6.83	0.173	0.25
	1.79	1.83	17.962	7.561	7.03	0.266	0.25
	1.97	1.79	31.969	7.919	6.99	0.465	0.36
	2.38	1.73	66.420	8.798	7.16	0.819	0.36
K	1.22	2.14	6.977	5.076	4.60	0.238	0.25
	1.33	1.91	7.960	5.503	5.05	0.227	0.25
	1.37	1.88	10.226	5.818	5.29	0.264	0.25
	1.41	1.84	13.479	6.014	5.34	0.337	0.25
	1.46	1.79	18.162	6.353	5.51	0.422	0.36
	1.52	1.75	25.549	6.684	5.54	0.572	0.36
	1.66	1.70	38.865	7.442	5.97	0.736	0.36
	1.77	1.65	62.428	7.699	5.40	1.150	0.50

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Table 22-a. Rotor and Stator Geometry and Velocity Diagram Data for Reference Designs

76	77a	77b	78	79a	79b	80	81	82	83	84
Rotor Blade Width (Axial Pitchline Component)	Stator Flow Passage Area					Stator Inlet		Stator Exit		Absolute C_o
	Inlet		Throat	Exit		OD	ID	OD	ID	
	Axial	Normal to Flow	Normal to Flow	Normal to Flow	Axial					
(in.)	(ft^2)	(ft^2)	(ft^2)	(ft^2)	(ft^2)	(in.)	(in.)	(in.)	(in.)	(ft/sec)
					85 72				$\sqrt{(82)^2 - \frac{144\ (79)}{0.786}}$	
0.25	0.0295	0.0285	0.00682	0.00764	0.0295			7.215	6.83	1196.5
0.30	0.0295	0.0285	0.0148	0.0223	0.0860	7.215	6.83	8.495	7.51	1316.0
0.25	0.0311	0.0300	-	0.00805	0.0311			5.92	5.42	949.7
0.25	0.0311	0.0300	0.0123	0.0127	0.0490	5.92	5.42	6.61	5.90	1033.0
0.36	0.0490	0.0473	0.0254	0.0304	0.1176	6.61	5.90	7.406	5.77	1105.7
0.25	0.0232	0.0224	-	0.00600	0.0232			6.297	5.95	1389.0
0.25	0.0232	0.0224	-	0.00683	0.0264	6.297	5.95	7.175	6.83	1598.5
0.25	0.0264	0.0255	-	0.0109	0.0423	7.175	6.83	7.561	7.03	1643.0
0.36	0.0423	0.0409	-	0.0196	0.0756	7.561	7.03	7.919	6.99	1634.0
0.36	0.0756	0.0730	0.0350	0.0369	0.1425	7.919	6.99	8.798	7.16	1801.0
0.25	0.0251	0.0242	-	0.00650	0.0251			5.076	4.60	1073.5
0.25	0.0251	0.0242	-	0.00676	0.0261	5.076	4.60	5.503	5.05	1179.2
0.25	0.0261	0.0252	-	0.00828	0.0320	5.503	5.05	5.818	5.29	1235.
0.25	0.0320	0.0309	-	0.0108	0.0417	5.818	5.29	6.014	5.34	1248.
0.36	0.0417	0.0403	-	0.0141	0.0545	6.014	5.34	6.353	5.51	1287.
0.36	0.0545	0.0526	-	0.0197	0.0763	6.353	5.51	6.684	5.54	1295.
0.36	0.0763	0.0737	-	0.0279	0.1077	6.684	5.54	7.442	5.97	1395.
0.50	0.1077	0.1040	-	0.0425	0.1643	7.442	5.97	7.699	5.40	1468.

3

ns

(82)	(83)	(84)	(85)	(86)	(87)
Stator Exit		Stator Exit Velocity			Inlet Nozzle Angle α_1
OD (in.)	ID (in.)	Absolute C_0 (ft/sec)	Axial Component (ft/sec)	Tangential Component (ft/sec)	(deg)
	$\sqrt{(82)^2 - \frac{144\ (79)}{0.786}}$		0.259 (84)	0.966 (84)	$\sin^{-1} \frac{(85)}{(84)}$
7.215	6.83	1196.5	310	1156	15
8.495	7.51	1316.0	341	1271	15
5.92	5.42	949.7	246	917	15
6.61	5.90	1033.0	268	998	15
7.406	5.77	1105.7	286	1068	15
6.297	5.95	1389.0	359	1340	15
7.175	6.83	1598.5	414	1542	15
7.561	7.03	1643.0	425	1587	15
7.919	6.99	1634.0	423	1578	15
8.798	7.16	1801.0	466	1739	15
5.076	4.60	1073.5	278	1037	15
5.503	5.05	1179.2	305	1139	15
5.818	5.29	1235.0	320	1193	15
6.014	5.34	1248.5	323	1206	15
6.353	5.51	1287.4	333	1244	15
6.684	5.54	1295.0	335	1251	15
7.442	5.97	1395.5	361	1348	15
7.699	5.40	1468.2	380	1418	15

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Table 22-b. Rotor and Stator Geometry a

(88)	(89)	(90)	(91)	(92)	(93)	(95)	(96)	(9
Rotor Tip								
Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)	Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Ro Bla In Ang (de
$Cs = \frac{300\pi}{12}$ (82) $K = \frac{400\pi}{12}$ (82)	(86) − (88)	$\tan^{-1}$ (85)/(89)	$\sqrt{(85)^2 + (89)^2}$	(89) − (88)	$\tan^{-1}$ (85)/(92)	$Cs = \frac{300\pi}{12}$ ((74)+(75)) $K = \frac{400\pi}{12}$ ((74)+(75))	(86) − (95)	$\tan^{-1}$ (85)/
568.6	587.4	27.8	664.2	18.7	86.5	552.9	603.1	27.
677.8	593.2	29.9	684.2	−84.6	103.1	633.8	637.2	28.
467.3	449.7	28.7	512.6	−17.6	94.9	446.1	470.9	27.
424.6	473.4	29.5	544.0	−51.3	100.2	494.0	504.0	28.
596.9	471.1	31.3	551.1	−125.8	114.0	524.6	543.4	27.
658.7	681.3	27.8	770.1	22.6	86.4	640.9	699.1	27.
752.9	789.1	27.7	891.1	36.1	85.0	734.1	807.9	27.
796.9	790.1	28.3	897.1	−6.8	90.1	766.5	820.4	27.
837.8	740.2	29.7	852.6	−97.5	102.0	785.4	792.6	28.
942.5	796.5	30.3	922.8	−146.0	107.6	846.1	892.9	31.
532.0	505.0	28.8	576.5	−27.0	95.5	506.8	530.2	27.
577.0	562.0	28.5	639.4	−15.0	92.2	552.9	586.1	27.
611.6	581.4	28.8	663.7	−30.1	95.6	582.2	610.8	27.
634.6	571.4	29.4	656.4	−63.2	101.9	596.9	609.1	27.
672.3	571.7	30.2	661.6	−100.6	106.2	625.2	618.8	28.
710.0	541.0	31.8	636.3	−169.0	116.2	645.1	605.9	28.
795.9	552.1	33.2	659.7	−243.7	123.0	710.0	638.0	29.
837.8	580.2	33.2	693.6	−257.6	124.9	701.6	716.4	28.

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Rotor and Stator Geometry and Velocity Diagram Data for Reference Designs

(95)	(96)	(97)	(98)	(99)	(100)	(101)	(102)	(103)	(104)
Pitch Line						Rotor Blade R			
Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)	Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relativ Inlet Velocit (ft/sec
$Cs = \frac{300\pi}{12}(74) + (75)$ $K = \frac{400\pi}{12}(74) + (75)$	$(86) - (95)$	$\tan^{-1}\frac{(85)}{(96)}$	$\sqrt{(85)^2 + (96)^2}$	$(96) - (95)$	$\tan^{-1}\frac{(85)}{(99)}$	$Cs = \frac{300\pi}{12}(74)$ $K = \frac{400\pi}{12}(74)$	$(86) - (101)$	$\tan^{-1}\frac{(85)}{(102)}$	$\sqrt{(85)^2 + (102)^2}$
552.9	603.1	27.2	678.1	50.2	80.8	536.4	619.6	26.6	692.8
633.8	637.2	28.2	722.7	3.4	89.4	589.8	681.2	26.6	761.8
446.1	470.9	27.6	531.3	24.8	84.2	425.7	491.3	26.6	549.5
494.0	504.0	28.0	570.8	10.0	87.9	463.4	534.6	26.6	598.0
524.6	543.4	27.8	614.0	18.7	86.2	453.2	614.8	25.0	678.1
640.9	699.1	27.2	785.9	58.2	80.8	622.0	718.0	26.6	802.7
734.[illegible]	807.9	27.1	907.8	73.8	79.9	715.2	826.8	26.6	924.6
766.5	820.4	27.4	924.0	53.9	82.8	736.2	850.8	26.5	951.1
785.4	792.6	28.1	898.4	7.2	89.0	732.0	846.0	26.6	945.9
846.1	892.9	31.5	1007.2	46.7	84.3	749.8	989.2	25.2	1093.5
506.8	530.2	27.7	598.6	23.3	85.2	481.7	555.3	26.6	621.0
552.9	586.1	27.5	660.7	33.2	83.8	528.8	610.2	26.6	682.1
582.2	610.8	27.6	689.5	28.5	84.9	554.0	639.0	26.6	714.7
596.9	609.1	27.9	689.4	12.2	87.8	559.2	646.8	26.5	723.0
625.2	618.8	28.3	702.7	-6.4	91.9	577.0	667.0	26.5	745.5
645.1	605.9	28.9	692.4	-39.1	96.3	580.1	670.8	26.5	749.8
710.0	638.0	29.5	733.1	-72.0	101.7	625.2	722.8	26.5	808.0
701.6	716.4	28.0	810.9	14.8	87.8	565.5	852.5	24.0	933.4

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(102)	(103)	(104)	(105)	(106)
Rotor Blade Root				
Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)
(101) − (86)	$\tan^{-1}$ (85)/(102)	$\sqrt{(85)^2 + (102)^2}$	(101) − (102)	$\tan^{-1}$ (85)/(105)
619.6	26.6	692.8	83.2	75.0
681.2	26.6	761.8	91.3	75.0
491.3	26.6	549.5	65.6	75.1
534.6	26.6	598.0	71.2	75.1
614.8	25.0	678.1	161.6	60.5
718.0	26.6	802.7	95.9	75.0
826.8	26.6	924.6	111.5	74.9
850.8	26.5	951.1	114.6	74.9
846.0	26.6	945.9	114.0	74.9
989.2	25.2	1093.5	239.4	62.8
555.3	26.6	621.0	73.6	75.2
610.2	26.6	682.1	81.3	75.1
639.0	26.6	714.7	85.1	75.1
646.8	26.5	723.0	87.6	74.8
667.0	26.5	745.5	90.0	74.9
670.8	26.5	749.8	90.7	74.8
722.8	26.5	808.0	97.6	74.9
852.5	24.0	933.4	287.0	52.9

Table 23. Data for Details of Turbine Buckets
(See Fig. 35 for definition of symbols)

Fluid	Stage No.	a^* (in.)	J (in.)	$\beta_{2\,tip}$ (deg)	$\beta_{2\,root}$ (deg)	r (in.)	J′ (in.)	Number of Blades	Root Area of Blade (in.^{2})
Cesium	1	0.072	0.250	27.8	26.6	0.140	0.248	153	0.0107
	2	0.086	0.300	29.9	26.6	0.167	0.293	141	0.0144
Cesium	1	0.060	0.250	28.7	26.6	0.140	0.247	122	0.0107
	2	0.067	0.250	29.5	26.6	0.140	0.243	132	0.0107
	3	0.076	0.360	31.3	25.0	0.200	0.343	91	0.0271
Potassium	1	0.063	0.250	27.8	26.6	0.140	0.248	134	0.0107
	2	0.072	0.250	27.7	26.5	0.140	0.248	153	0.0107
	3	0.076	0.250	28.3	26.4	0.140	0.247	158	0.0107
	4	0.080	0.360	29.7	26.6	0.201	0.291	110	0.0271
	5	0.090	0.360	30.3	25.2	0.200	0.346	113	0.0271
Potassium	1	0.051	0.250	28.8	26.6	0.140	0.247	103	0.0107
	2	0.055	0.250	28.5	26.6	0.140	0.247	113	0.0107
	3	0.058	0.250	28.8	26.6	0.140	0.247	119	0.0107
	4	0.061	0.250	29.4	26.5	0.040	0.243	120	0.0107
	5	0.064	0.360	30.2	26.5	0.201	0.259	87	0.0271
	6	0.067	0.360	31.8	26.5	0.201	0.343	87	0.0271
	7	0.076	0.360	33.2	26.5	0.201	0.339	94	0.0271
	8	0.080	0.500	33.2	24.0	0.274	0.460	62	0.0600

Table 24. Stator Blade Dimensional Data

Turbine	Stator No.	Rotor Spacing S (in.)	Stator OD D_o (in.)	Stator OD D_L (in.)	Stator Blade Height h_o (in.)	Stator Blade Height h_L (in.)	Blade Width w_o (in.)	Blade Width w_L (in.)	Blade Length (in.)	Number of Blades per Stage	Z_t[a] (in.)
2-Stage Cs	1	1.42[b]	7.215	7.215	0.193	0.193	0.25	0.25	0.82	40	0.76
	2	1.42	7.215	8.495	0.193	0.493	0.25	0.30	0.80	40	0.77
3-Stage Cs	1	1.25[b]	5.923	5.923	0.251	0.251	0.25	0.25	0.65	36	
	2	1.25	5.923	6.618	0.251	0.359	0.25	0.25	0.65	36	0.64
	3	1.30	6.618	7.406	0.359	0.818	0.25	0.36	0.65	36	0.62
5-Stage K	1	1.25[b]	6.297	6.297	0.1794	0.174	0.25	0.25	0.65	36	
	2	1.25	6.297	7.175	0.174	0.173	0.25	0.25	0.65	36	
	3	1.25	7.175	7.561	0.173	0.266	0.25	0.25	0.65	40	
	4	1.35	7.561	7.919	0.266	0.465	0.25	0.36	0.70	40	
	5	1.60	7.919	8.798	0.465	0.819	0.36	0.36	0.80	48	0.88
8-Stage K	1	1.25[b]	5.076	5.076	0.238	0.238	0.25	0.25	0.65	30	
	2	1.25	5.076	5.503	0.238	0.227	0.25	0.25	0.65	30	
	3	1.25	5.503	5.818	0.227	0.264	0.25	0.25	0.65	30	
	4	1.25	5.818	6.014	0.264	0.337	0.25	0.25	0.65	36	
	5	1.30	6.014	6.353	0.337	0.422	0.25	0.36	0.65	36	
	6	1.30	6.353	6.684	0.422	0.572	0.36	0.36	0.59	36	
	7	1.50	6.684	7.442	0.572	0.736	0.36	0.36	0.79	40	
	8	1.50	7.442	7.699	0.736	1.150	0.36	0.50	0.72	40	

[a] Z_t is given only for the definitely supersonic cases (See also Table 22a, columns 70 and 78).

[b] Dummy; used to define L for stator No. 1.

Table 25. Effects of the First Stage Temperature Drop on the Maximum Turbine Inlet Temperature Permitted by Creep in the First Stage Rotor

Fluid	First Stage Temperature Drop (°F)	First Stage Rotor Tip Speed From Baljé's Charts (ft/sec)	Stress for 1% Creep in 20,000 hr (psi)	Turbine Wheel Temperature (°F)	Stator Inlet Temperature (°F)
Potassium	205	664	10,500	2010	2215
	160	599	8,500	2035	2195
	115	513	6,180	2110	2225
	90	469	5,150	2160	2250
Cesium	820	805	17,300	1900	2720
	410	467	5,100	2160	2570
	270	384	3,500	2220	2490
	160	309	2,250	2350	2510

Table 26. Data for the Weights and Moments of Inertia of Rotor Elements for the Reference Designs of Table 19

Note: The dias of the stub shafts on the generator rotor and the turbine wheel hubs were taken as 3.0 in. The turbine stub shaft diameter was taken as 3.0 in. except at the bearings where the diameter was 2.4 in.

Case No.	Stage No. (or Section)	Turbine Rotor		Generator Rotor		Coupling Weight (lb)
		Weight (lb)	Inertia ($in \cdot lb_f \cdot sec^2$)	Weight (lb)	Inertia ($in \cdot lb_f \cdot sec^2$)	
1	Stub	10.72	0.029	13.0	0.0379	
	1	5.557	0.03700			
(Cs – 4 br)	2	6.353	0.05096	195	6.840	5.42
	3	7.9638	0.08740			
	Stub	2.26	0.00658	11.1	0.0322	
2	Stub	3.25	0.000947	10.4	0.0306	
	1	8.641	0.07773	195	6.840	
(Cs – 2 br)	2	9.639	0.1415			
	Stub	3.64	0.0106	11.1	0.0322	
3	Stub	3.9	0.01136	10.4	0.0306	
	1	5.557	0.03700			
(Cs – 2 br)	2	6.405	0.05111	195	6.840	
	3	7.8336	0.08702			
	Stub	3.51	0.0122	10.88	0.0317	
4	Stub	7.08	0.01785	12.1	0.03525	
	1	6.5999	0.04800			
	2	7.4152	0.07358			
	3	7.8981	0.08527	155	4.632	6.5
(K – 4 br)	4	9.8523	0.12801			
	5	11.8653	0.17588			
	Stub	5.7	0.01138	10.9	0.0318	
5	Stub	9.45	0.0273	13.0	0.0379	
	1	4.7092	0.023311			
	2	5.1874	0.029835			
	3	5.6172	0.035201			
(K – 4 br)	4	5.5732	0.037092			
	5	7.1983	0.057775	155	4.632	6.5
	6	7.5224	0.065011			
	7	8.7677	0.092883			
	8	9.8498	0.12663			
	Stub	6.12	0.01214	11.1	0.0322	
6	Stub	9.45	0.0243	10.4	0.0306	
	1	6.2094	0.04686			
	2	7.4152	0.07358			
	3	7.7679	0.08489	155	4.632	
(K – 2 br)	Stub	3.64	0.0106			
	Stub	3.38	0.00985			
	4	10.4511	0.12975			
	5	11.6050	0.17513			
	Stub	3.64	0.0106	10.4	0.0306	

Table 27. Summary of Size and Weight Data for Reference Design Turbine-Generator Units

Working fluid	Cs	Cs	Cs	K	K	K
Number of stages	3	2	3	5	8	3+2
Number of bearings	4	2	2	4	4	2
RPM	18,000	18,000	18,000	24,000	24,000	24,000
Turbine diameter, in.	16	16	16	20	20	20
Turbine length, in.	12	6	7	20	25	13
Turbine weight, lb	190	100	120	540	680	350
Generator diam, in.	23	23	23	21	21	19
Generator length, in.	20	20	20	19	19	19
Generator weight, lb	690	690	690	550	550	550
Total weight of turbine-generator unit, lb	880	790	810	1090	1230	900

Table 28. Summary of Data from Turbine Rotor and Bearing Dynamics and Creep Studies at MTI for ORNL[21]

Case Number	1	2	3	4	5	6
Working fluid	Cs	Cs	Cs	K	K	K
Number of stages in turbine	3	2	3	5	8	3/2[a]
Number of bearings	4	2	2	4	4	2
Average temperature of 1st stage rotor	1740	1740	1880	1990	2050	1990
Rotor rpm	18,000	18,000	18,000	24,000	24,000	24,000
O.D. of 1st stage rotor, in.	5.923	7.215	5.923	6.297	5.076	6.297
Tip speed of 1st stage rotor, ft/sec	413	467	413	581	420	581
Bearings:						
Journal diameter, in.	2	3	3	2	2	3
Journal length, in.	1.5	2.25	2.25	1.5	1.5	2.25
Journal temperature, °F	1330	830	830	1330	1330	830
Diametral clearance, in.	0.0030	0.0045	0.0045	0.0030	0.0030	0.0045
Approximate critical speeds:						
1st, rpm	7,000	5,500	5,500	6,500	6,500	5,800
2nd, rpm	14,000			15,000	15,000	8,300
3rd, rpm	>30,000	>30,000	>30,000	>40,000	>40,000	27,000
Maximum journal orbit amplitude:[b]						
1st critical speed, mils	0.01	0.005	0.006	0.01	0.01	0.01
2nd critical speed, mils	0.024			0.036	0.036	0.015
Design speed, mils	0.032	0.015	0.019	0.055	0.055	0.075
Friction horsepower, hp	4.0	8	8	4.4	4.4	12.6
Average tangential stress, psi	9,100	10,900	9,100	14,200	12,700	14,200
Rim growth (circumferential), in.	<<0.0027	<<0.003	<0.0027	0.0891	Fracture	0.0891

[a]Three stages overhung at one end of generator and two at other.

[b]Maximum amplitude occurred in generator rather than in turbine bearings in four-bearing machines.

Table 29. Estimated Threshold of Damaging Impact Velocity for the Reference Turbine Systems*

Turbine Stage	Primary Drop Diam (μ)	Threshold Velocities (fps) for Various Values of VPN			
		190	260	400	500
2Cs - 2	1.	> 3000	> 3000	> 3000	> 3000
	5.	2876	> 3000	> 3000	> 3000
3Cs - 3	1.	> 3000	> 3000	> 3000	> 3000
	5.	> 3000	> 3000	> 3000	> 3000
5K - 5	8.	> 3000	> 3000	> 3000	> 3000
	20.	2083	2850	> 3000	> 3000
8K - 8	10.	> 3000	> 3000	> 3000	> 3000
	30.	1822	2493	> 3000	> 3000

*This table was excerpted from Ref. 22.

ORNL DWG. 68-12579

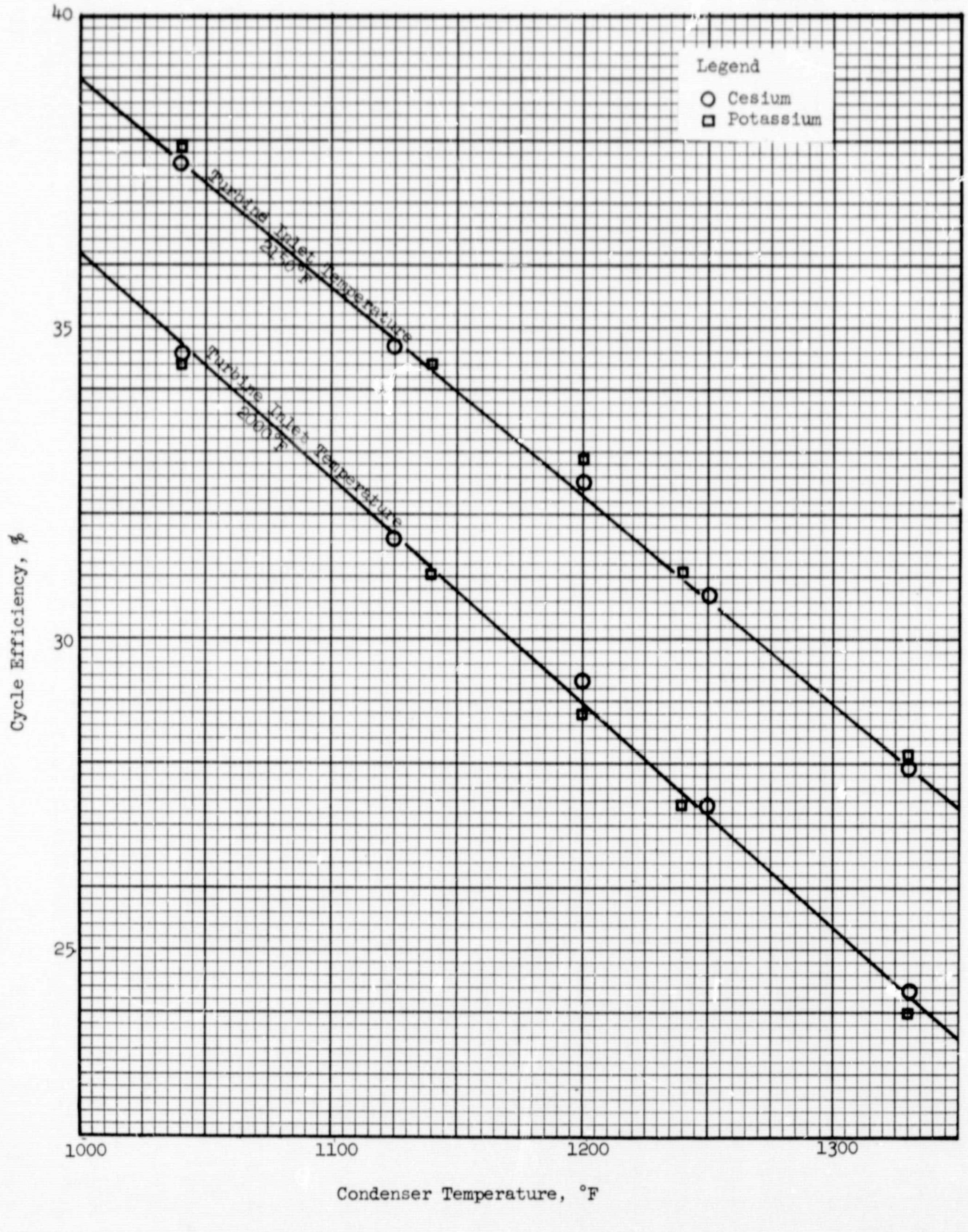


Fig. 1. Effects of Condenser Temperature on the Efficiency of a Series of Ideal Rankine Cycles.

ORNL DWG. 68-12580

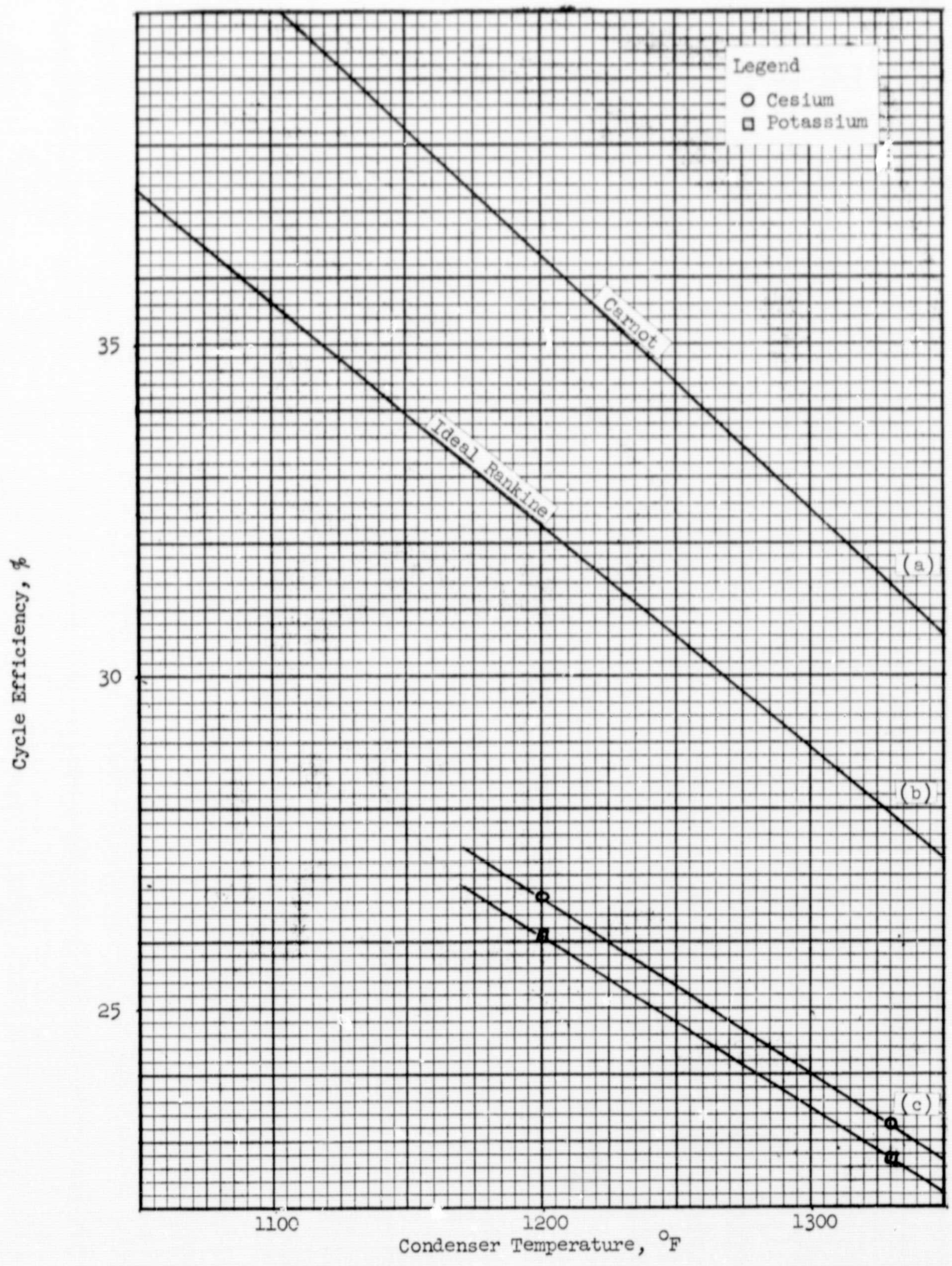


Fig. 2. Effects of Condenser Temperature on a Series of Cycles With a Turbine Inlet Temperature of 2150°F. (a) Ideal Carnot, (b) Ideal simple Rankine cycle, (c) Simple Rankine cycle with allowances for the aerodynamic losses included in Baljé's charts.

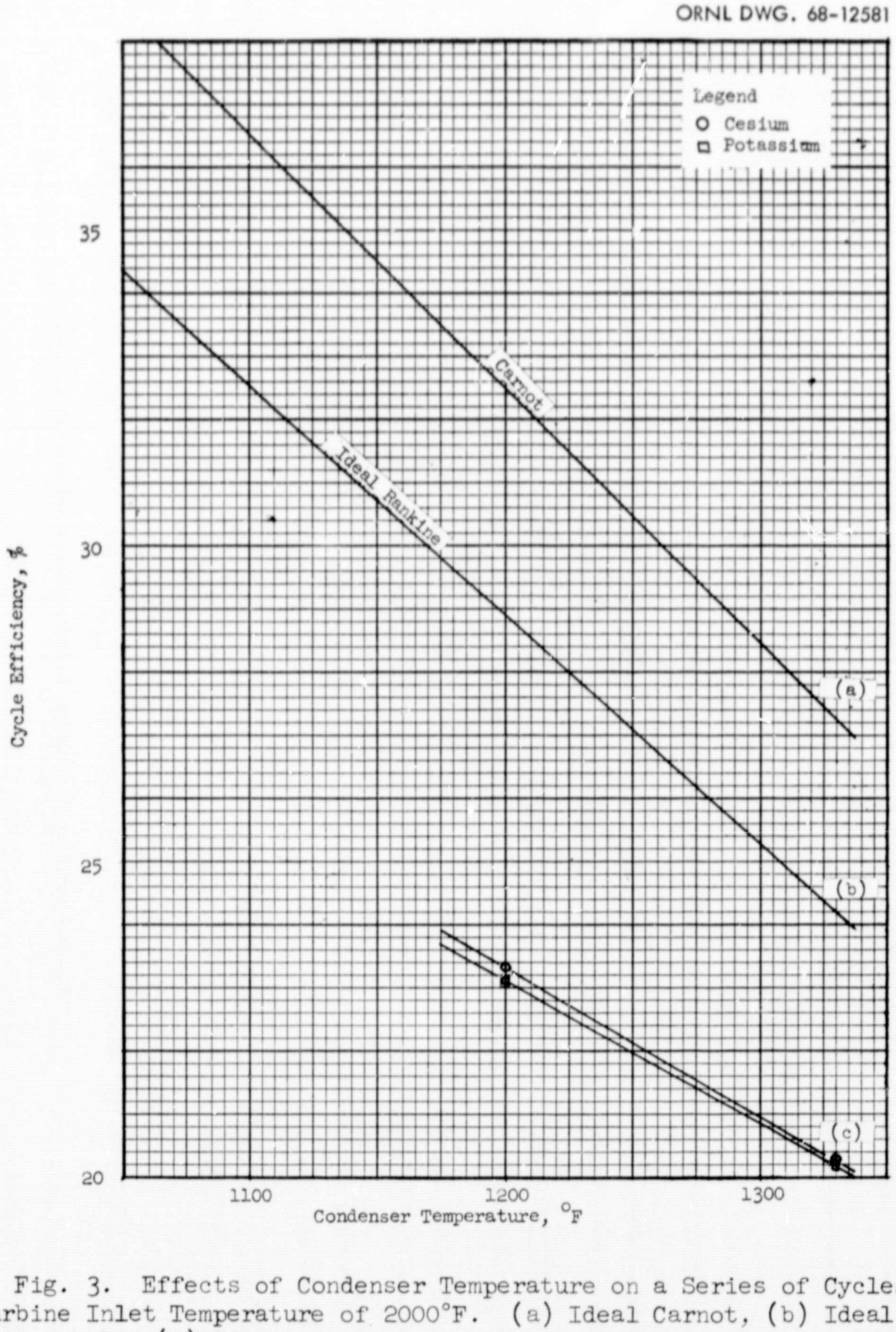
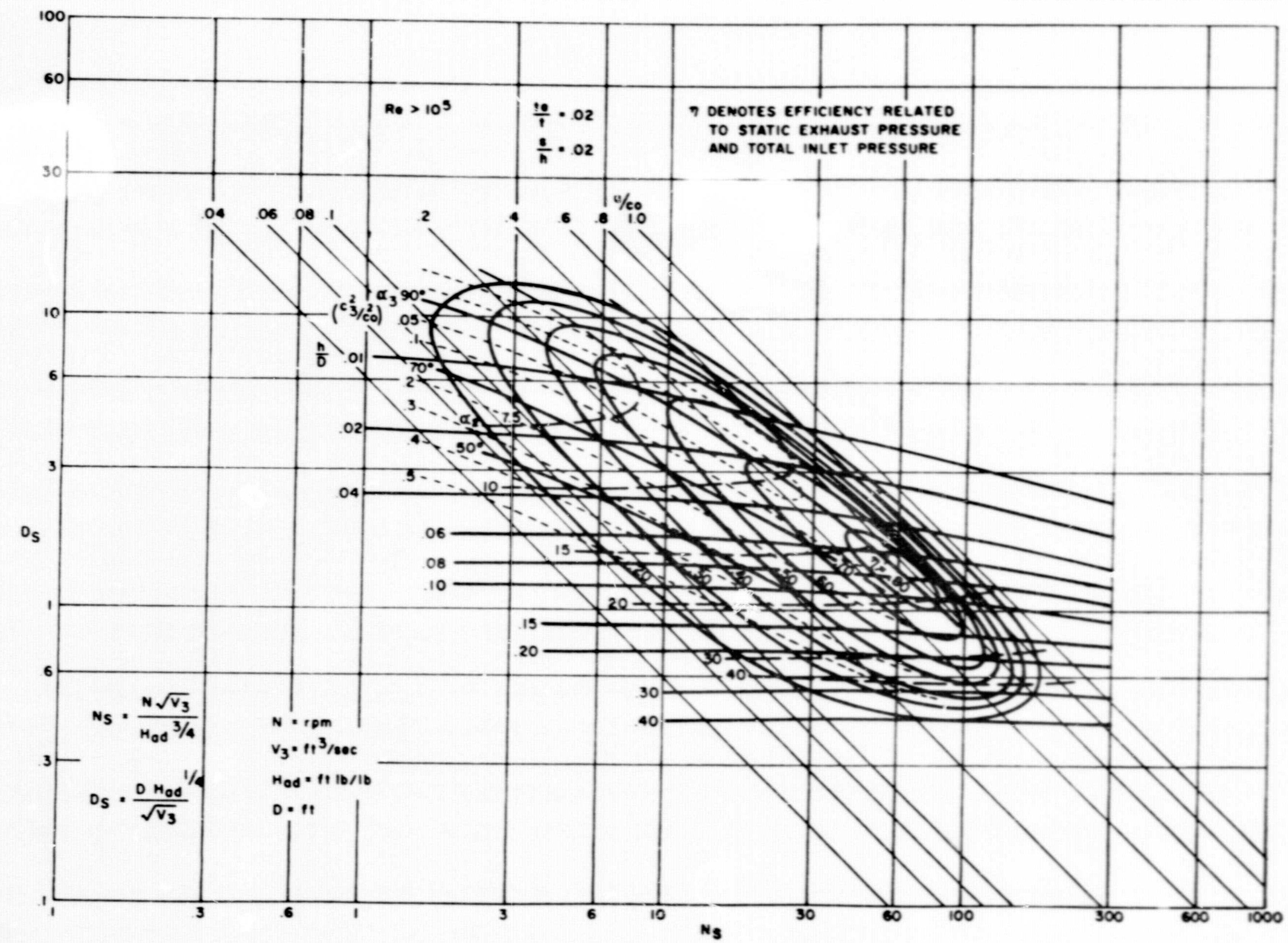


Fig. 3. Effects of Condenser Temperature on a Series of Cycles With a Turbine Inlet Temperature of 2000°F. (a) Ideal Carnot, (b) Ideal simple Rankine cycle, (c) Simple Rankine cycle with allowances for the aerodynamic losses included in Baljé's charts.

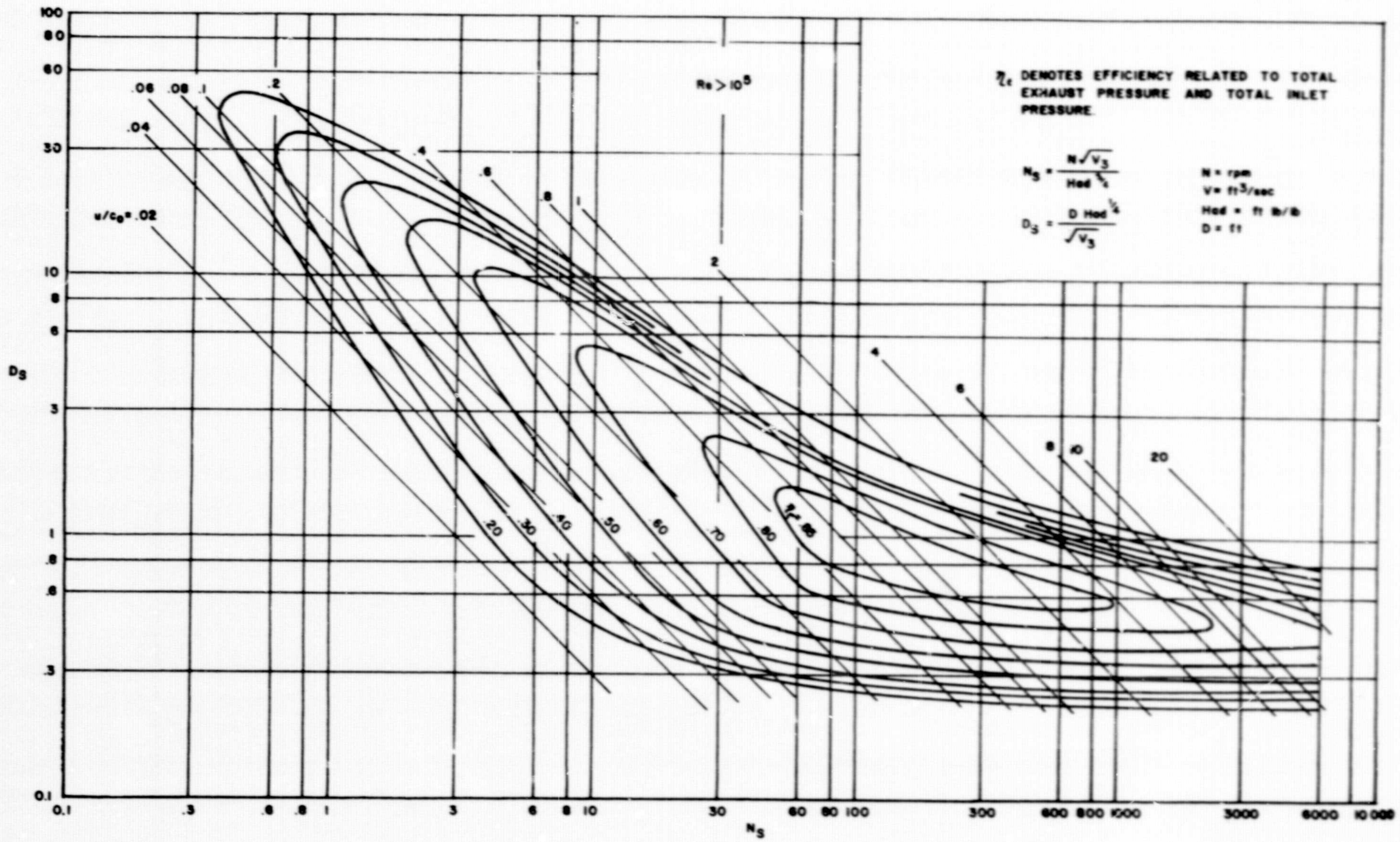
ORNL DWG. 67-1696



N_sD_s-diagrams for single-stage, full-admission, axial-impulse turbines

Fig. 4. N_sD_s-Diagrams for Single-Stage, Full-Admission, Axial-Impulse Turbines. (From Baljé, Ref. 15)

ORNL DWG. 67-1699



***N_sD_s*-diagram for single-disk turbines showing total efficiency**

Fig. 5. N_sD_s-Diagrams for Single-Disk Turbines Showing Total Efficiency. (From Baljé, Ref. 15)

ORNL DWG. 67-4986

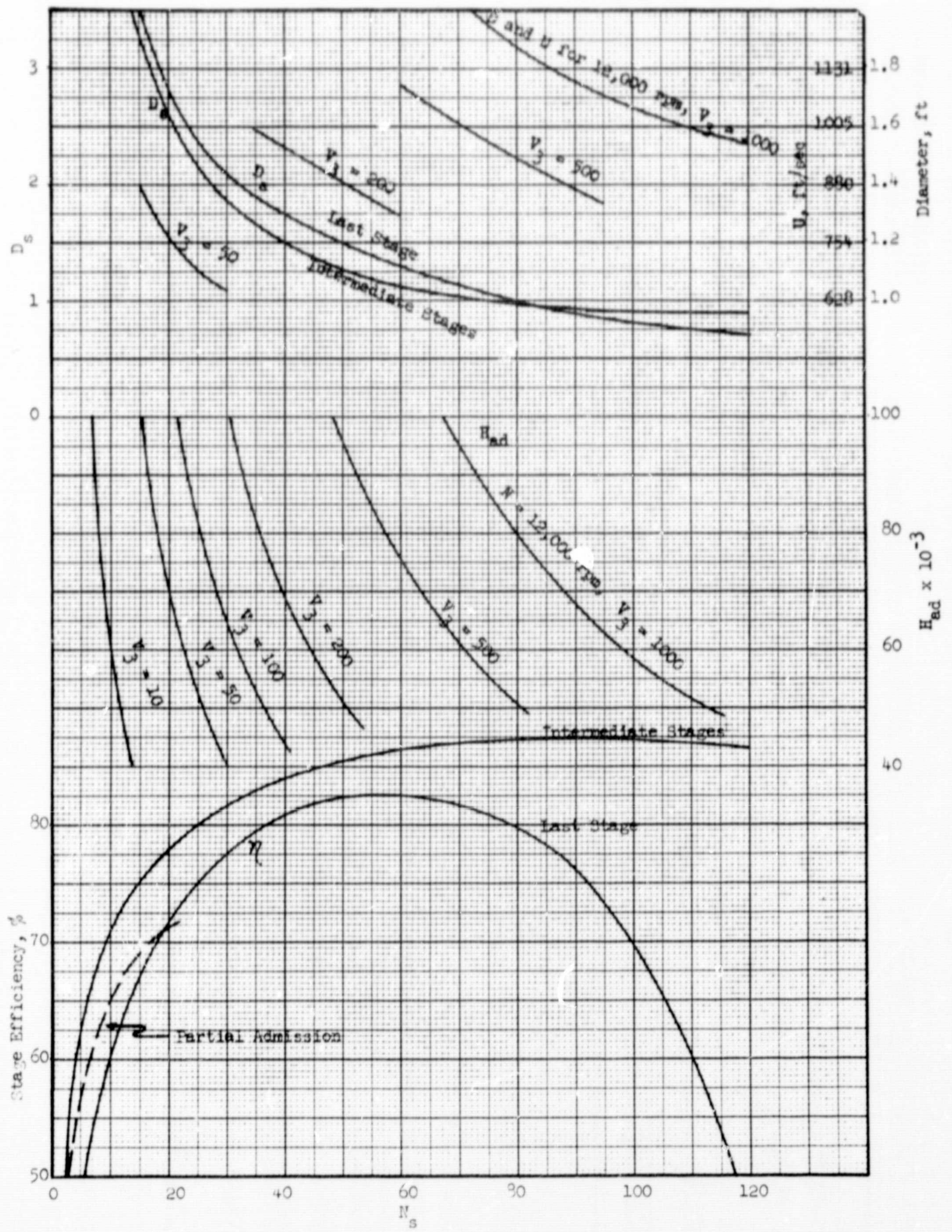


Fig. 6. Maximum Efficiency and the Corresponding D_s for any given N_s with Full Admission. Curves for D, U and H_{ad} for typical values of V_3 are also shown for N = 12,000 rpm.

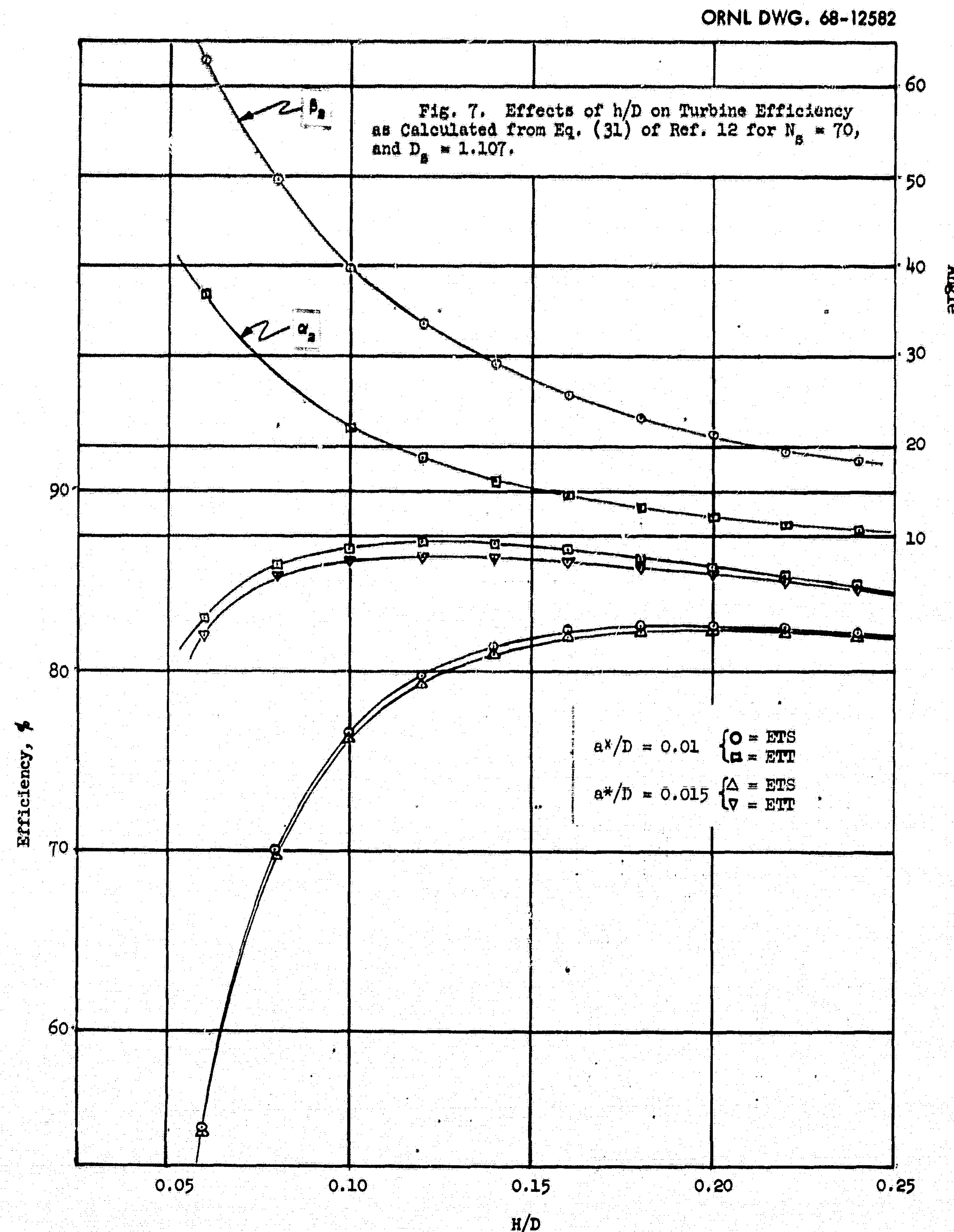


Fig. 7. Effects of h/D on Turbine Efficiency as Calculated from Eq. (31) of Ref. 12 for $N_s = 70$, and $D_s = 1.107$.

ORNL DWG. 68-9398

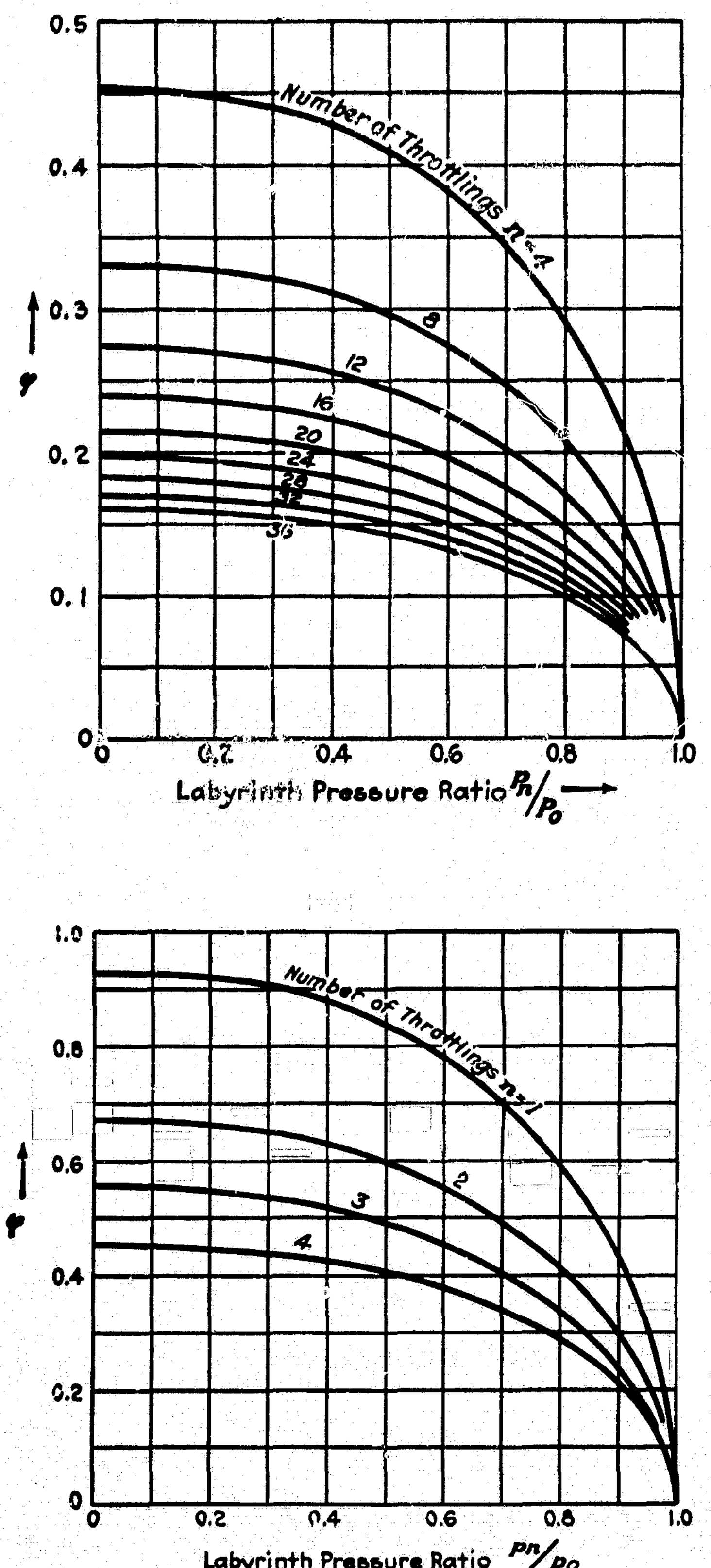


Fig. 8. Leakage Function φ for (a) Labyrinths With Four and More Throttlings, and (b) Labyrinths With One to Four Throttlings. (From Egli, Ref. 13)

ORNL DWG. 68-12583

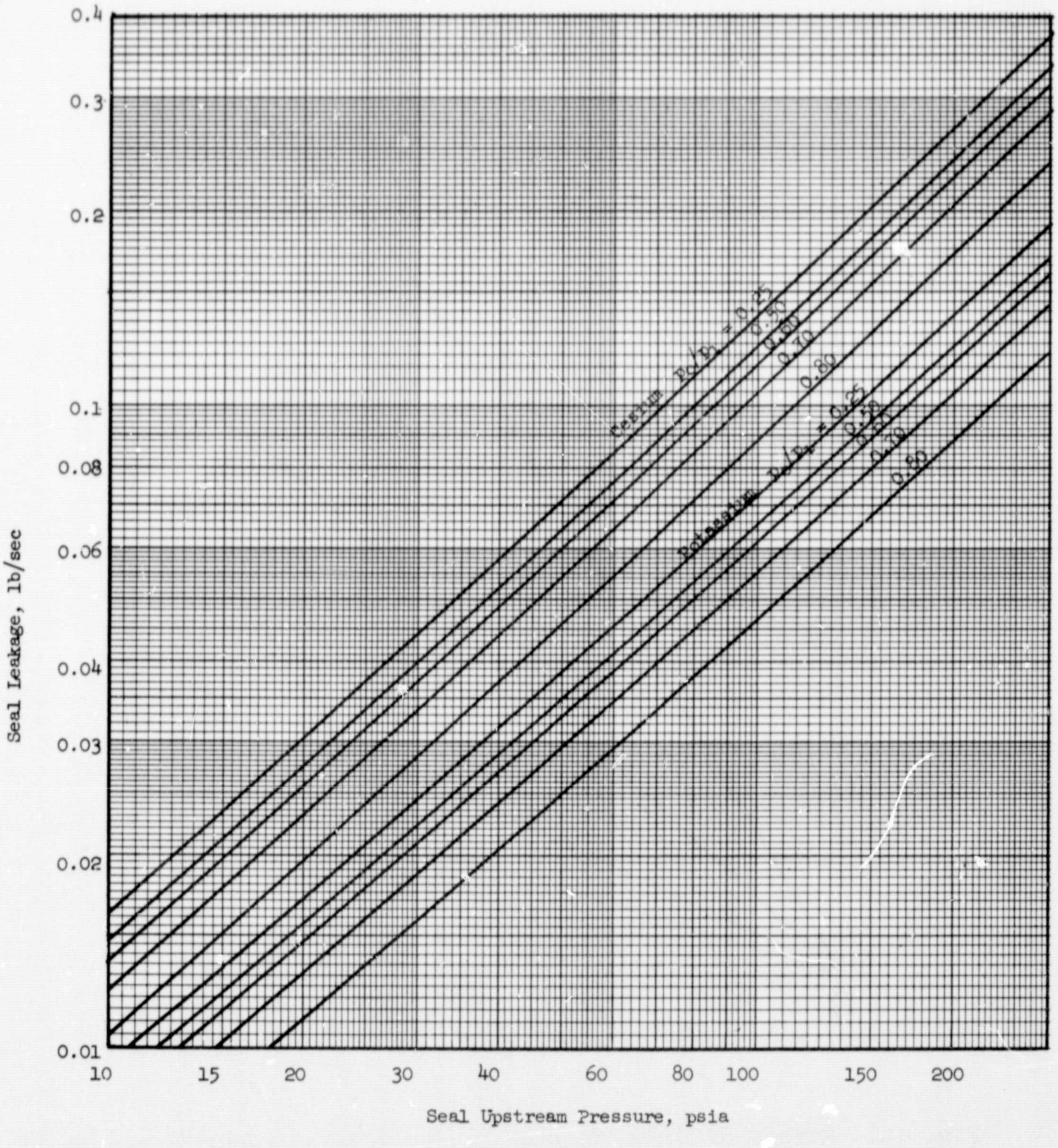


Fig. 9. Leakage Through 12-Land Labyrinth Seals on Straight Journals for 3.0 in. Journal Diameter and a Radial Clearance of 0.0055 in.

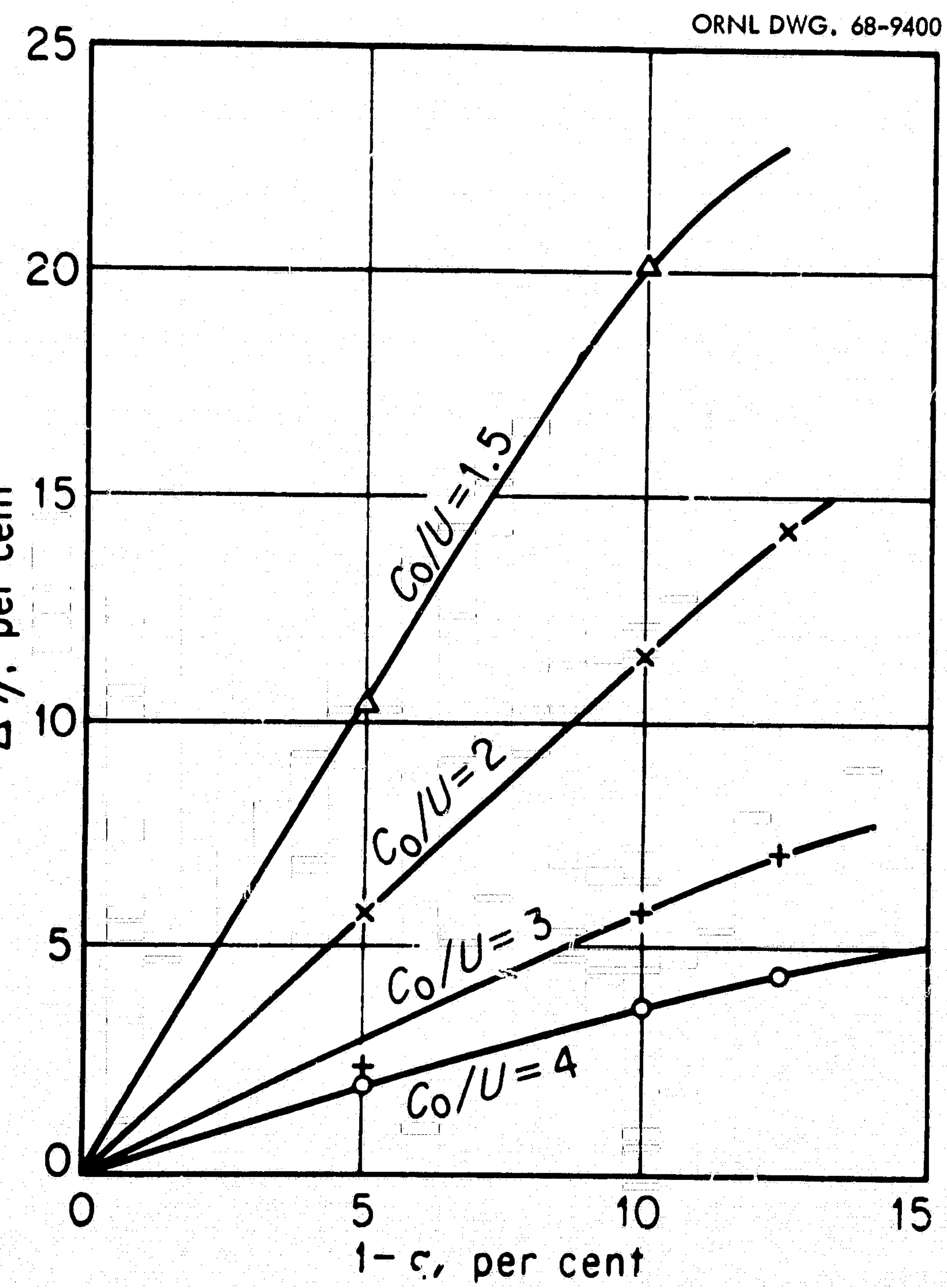


Fig. 10. Effect of Steam Wetness on the Efficiency of the Affected Turbine Stages. The parameter C_o/U is proportional to E_n/N^2D^2, with $C_o = 2E_n$. Abscissa is wetness fraction $(1 - q)$; ordinate drop in efficiency, $\Delta\eta$ (Csanady, Ref. 10)

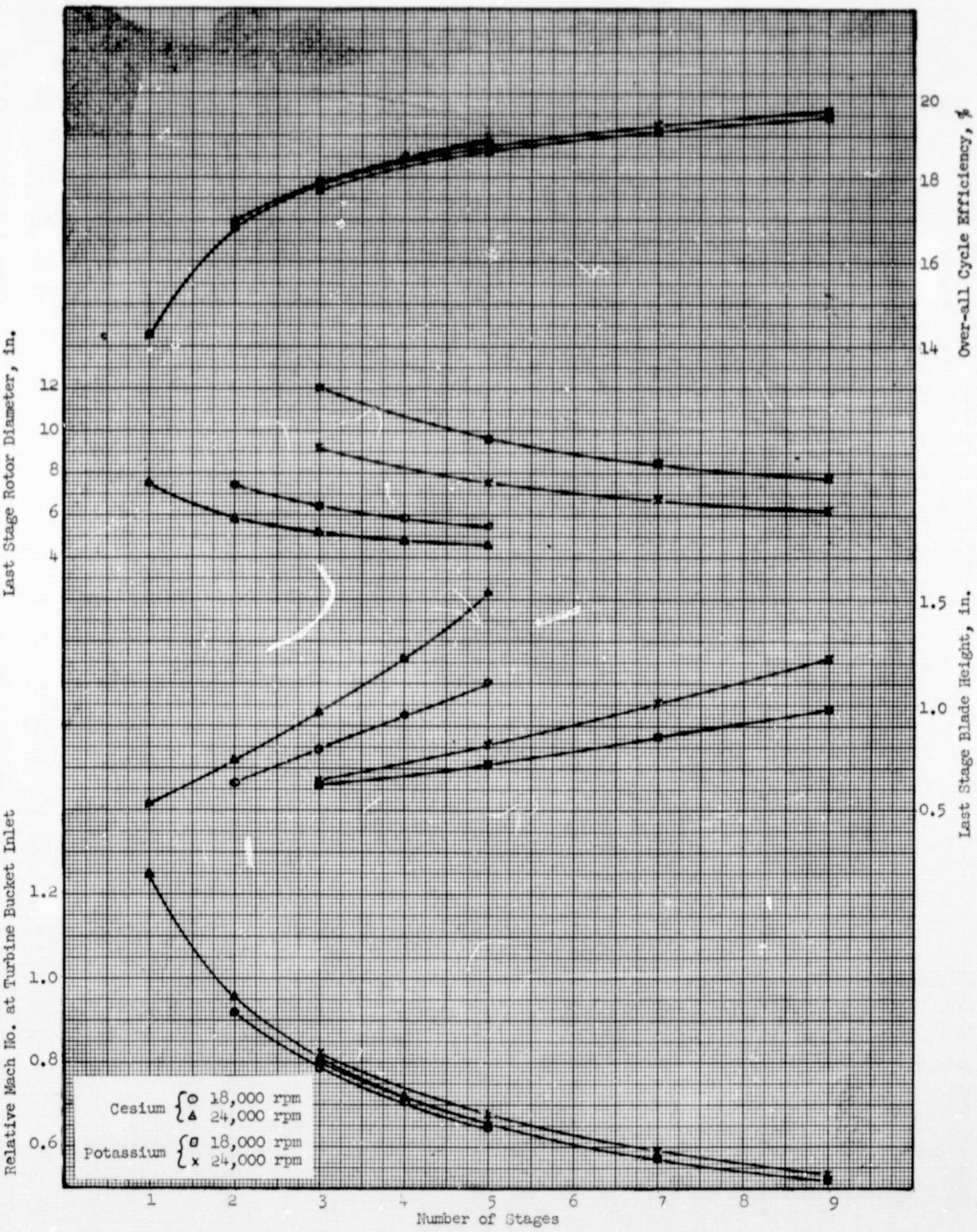


Fig. 11a. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Turbine inlet temperature 2150°F, turbine outlet temperature 1330°F.

ORNL DWG. 68-12585

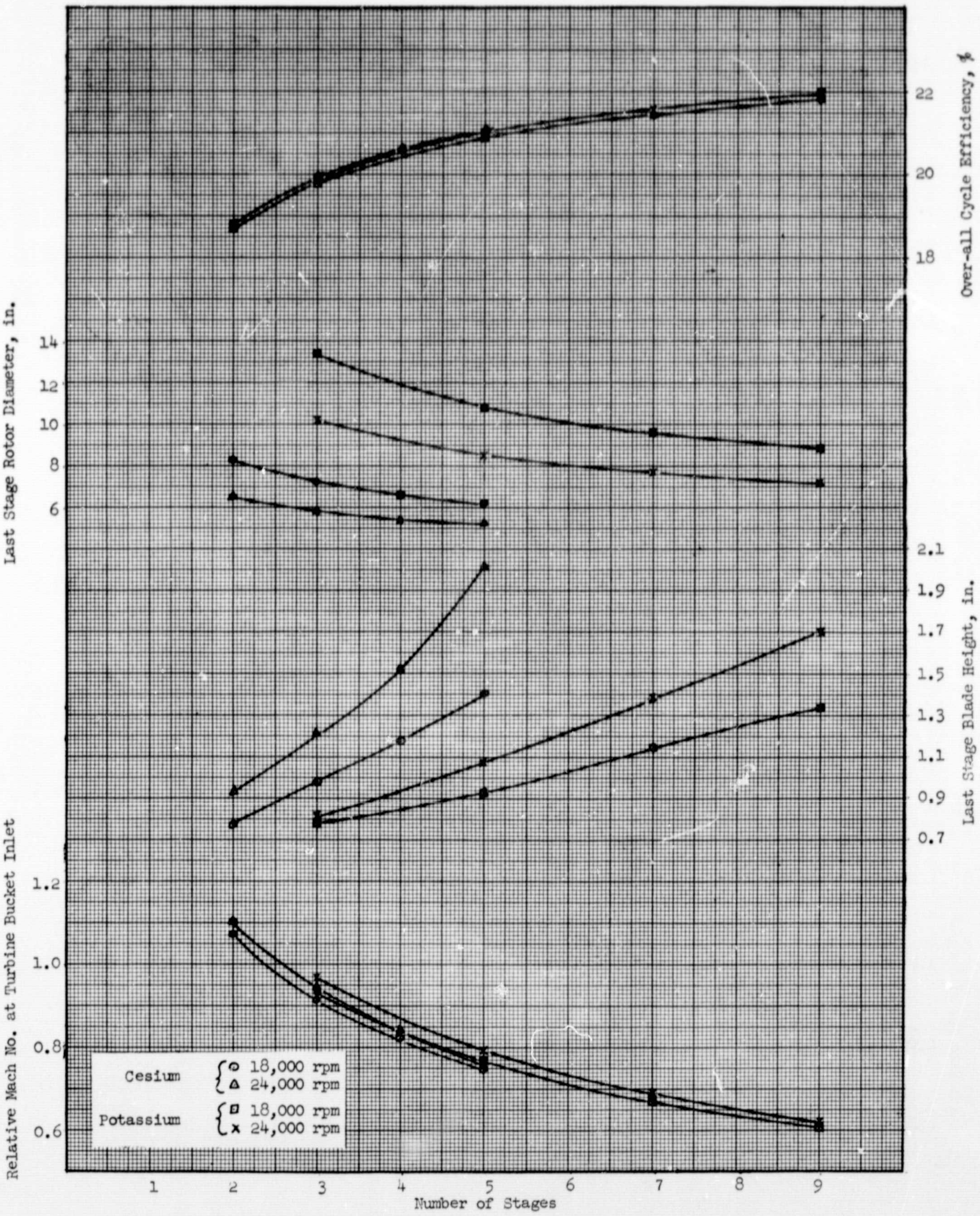


Fig. 11b. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating of Seal Leakage Losses. Turbine inlet temperature 2150°F, turbine outlet temperature 1200°F.

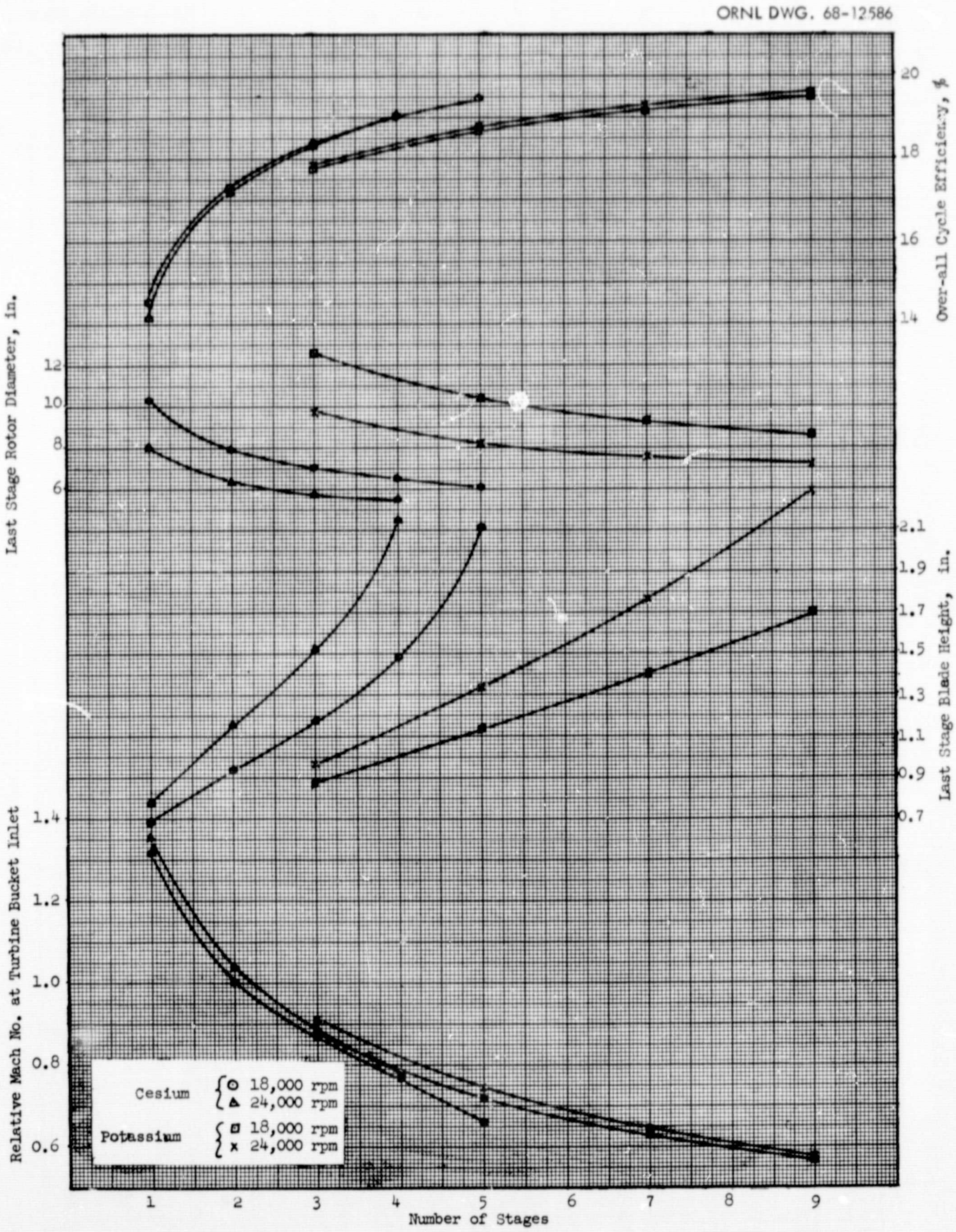


Fig. 11c. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Turbine inlet temperature 2000°F, Turbine outlet temperature 1200°F.

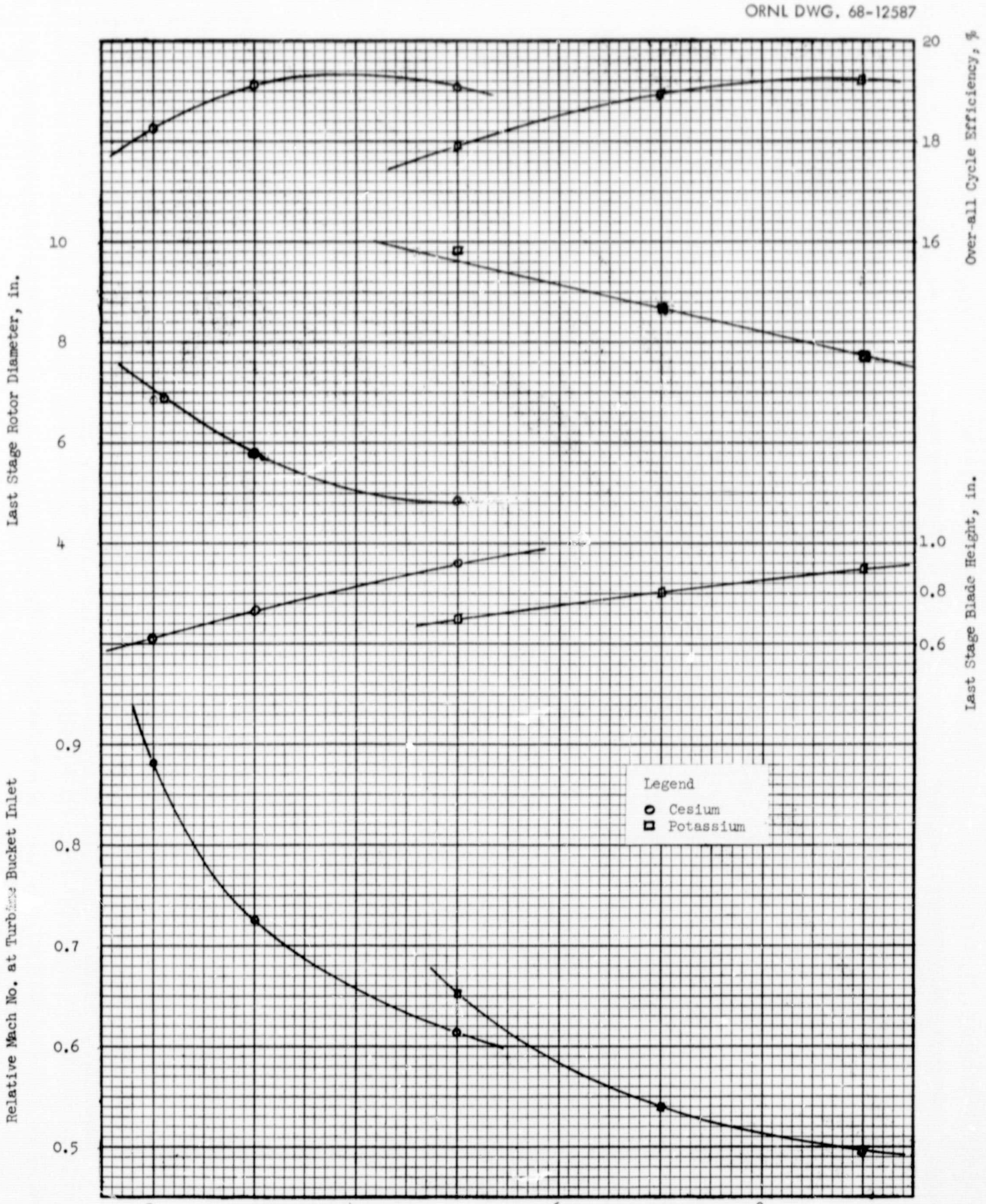


Fig. 12. Effects of Number of Stages on the Overall Thermal Efficiency, Size, and Inlet Mach Number of a Series of Cesium and Potassium Turbines Designed for 24,000 rpm With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. (T_{in} = 2150°F, T_{out} = 1330°F)

ORNL DWG. 68-12588

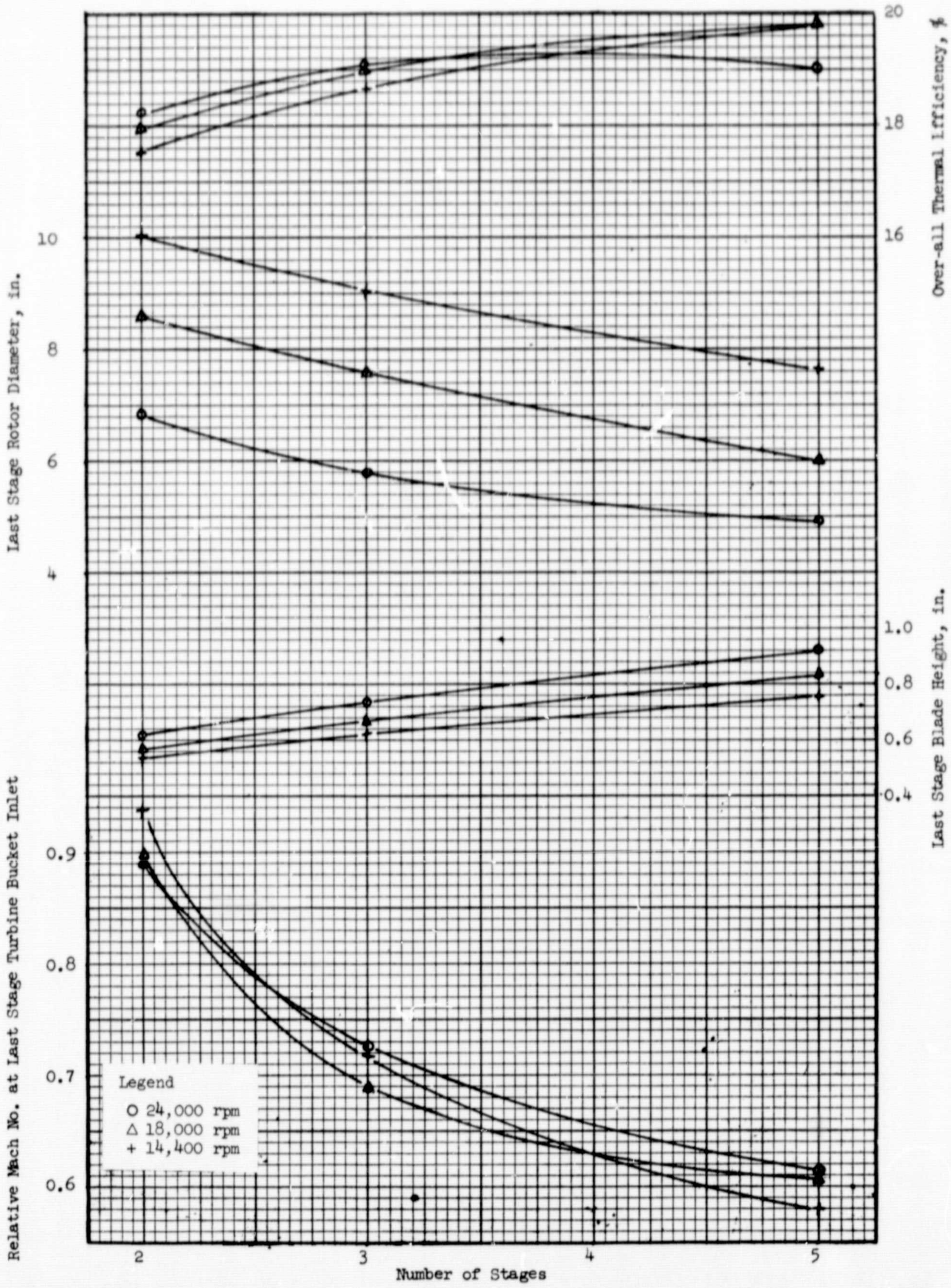


Fig. 13. Effects of Number of Stages and Design RPM on the Overall Cycle Efficiency, Size, and Rotor Blade Inlet Mach Number for a Series of Cesium Vapor Turbines With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. (T_{in} = 2150°F, T_{out} = 1330°F)

ORNL DWG. 68-12589

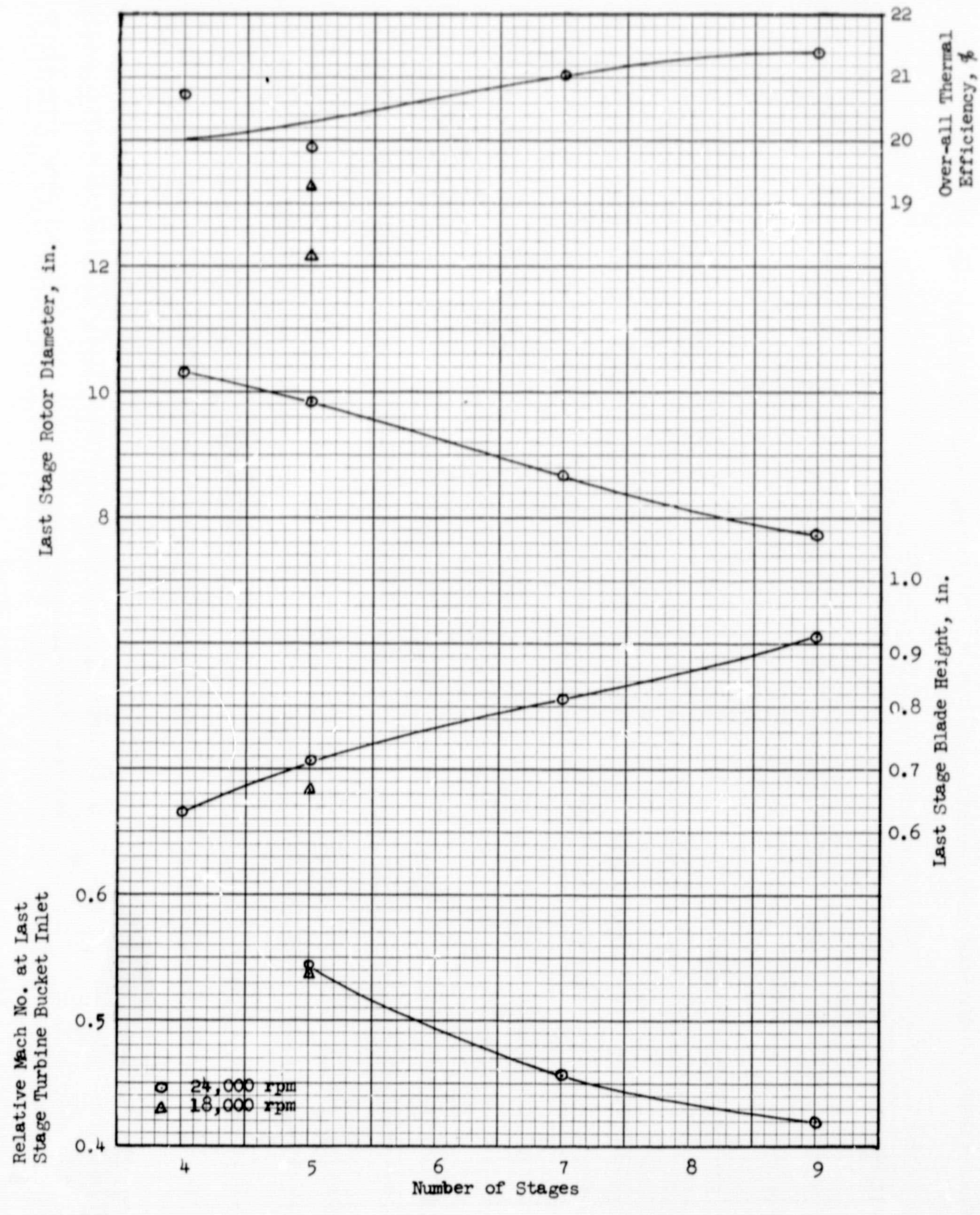


Fig. 14. Effects of Number of Stages and Design RPM on the Overall Cycle Efficiency, Size, and Rotor Blade Inlet Mach Number for a Series of Potassium Vapor Turbines With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. (T_{in} = 2150°F, T_{out} = 1330°F)

ORNL DWG. 68-2579

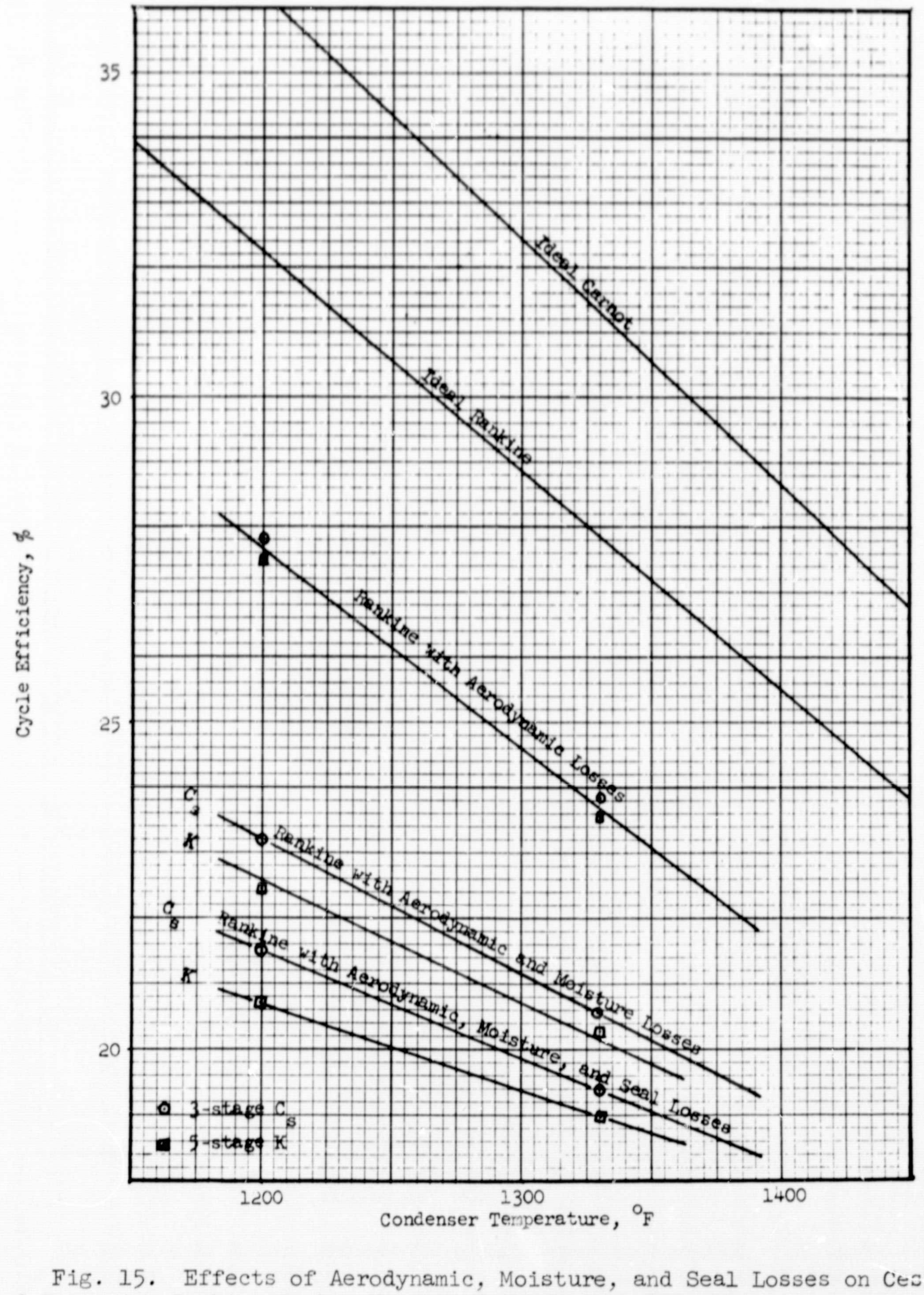


Fig. 15. Effects of Aerodynamic, Moisture, and Seal Losses on Cesium and Potassium Rankine Cycles With No Regenerative Feed Heating, a Turbine Inlet Temperature of 2150°F, a Turbine Outlet Temperature of 1330°F, and 25°F of Superheat.

ORNL DWG. 68-2580

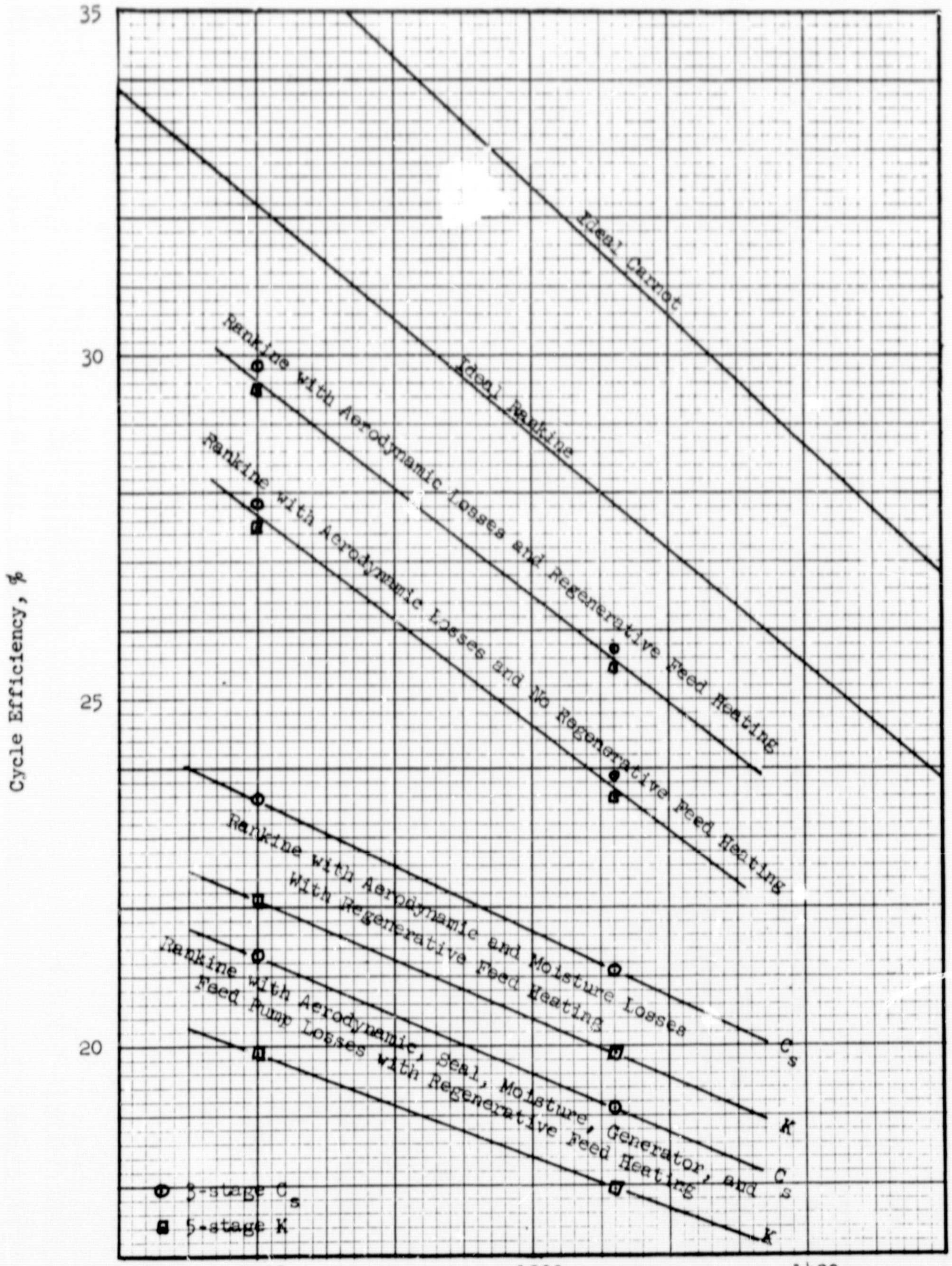
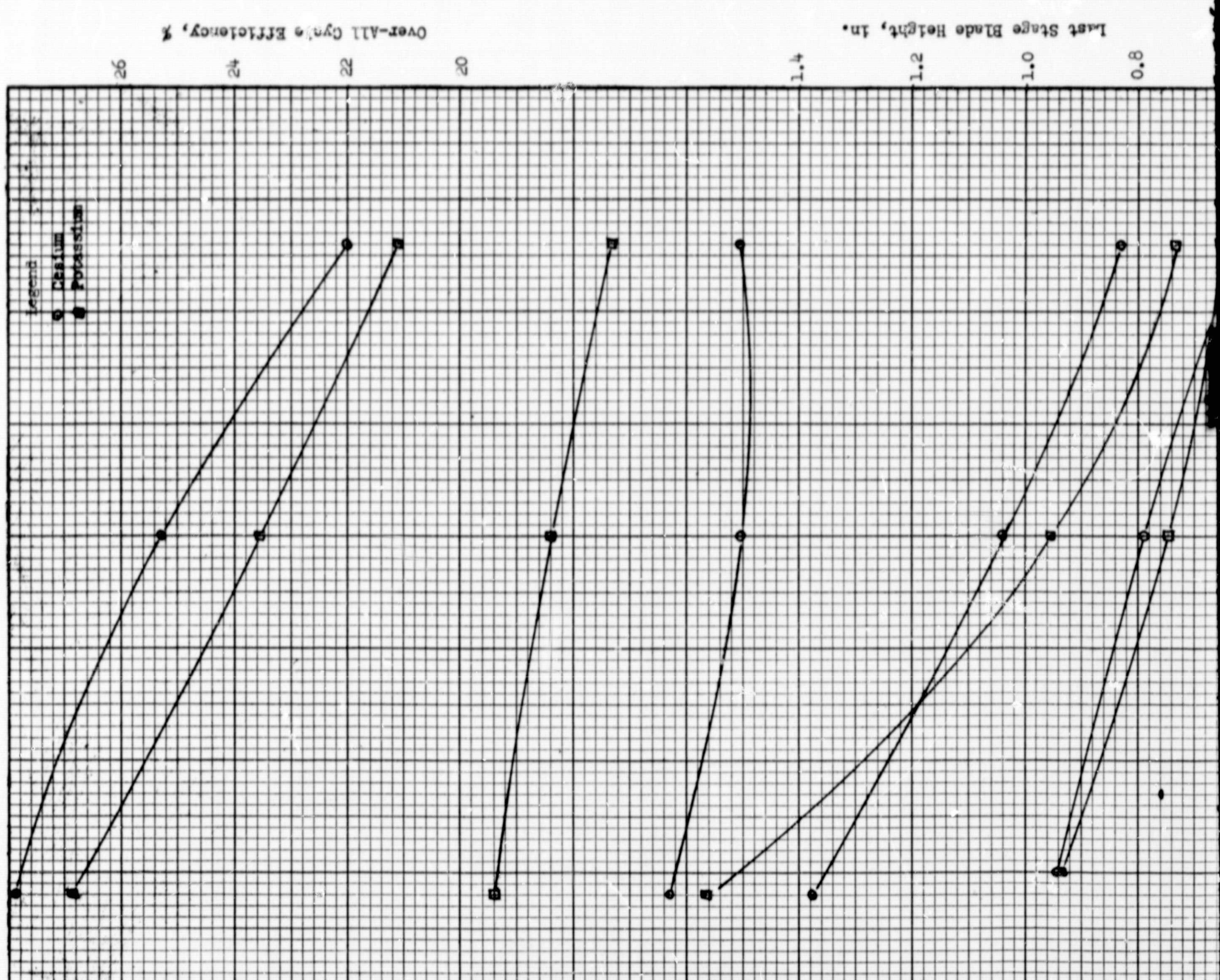


Fig. 16. Effects of Aerodynamic, Moisture, and Seal Losses on Cesium and Potassium Rankine Cycles With Regenerative Feed Heating, a Turbine Inlet Temperature of 2150°F, a Turbine Outlet Temperature of 1330°F, and 25°F of Superheat.

FOLDOUT FRAME 1



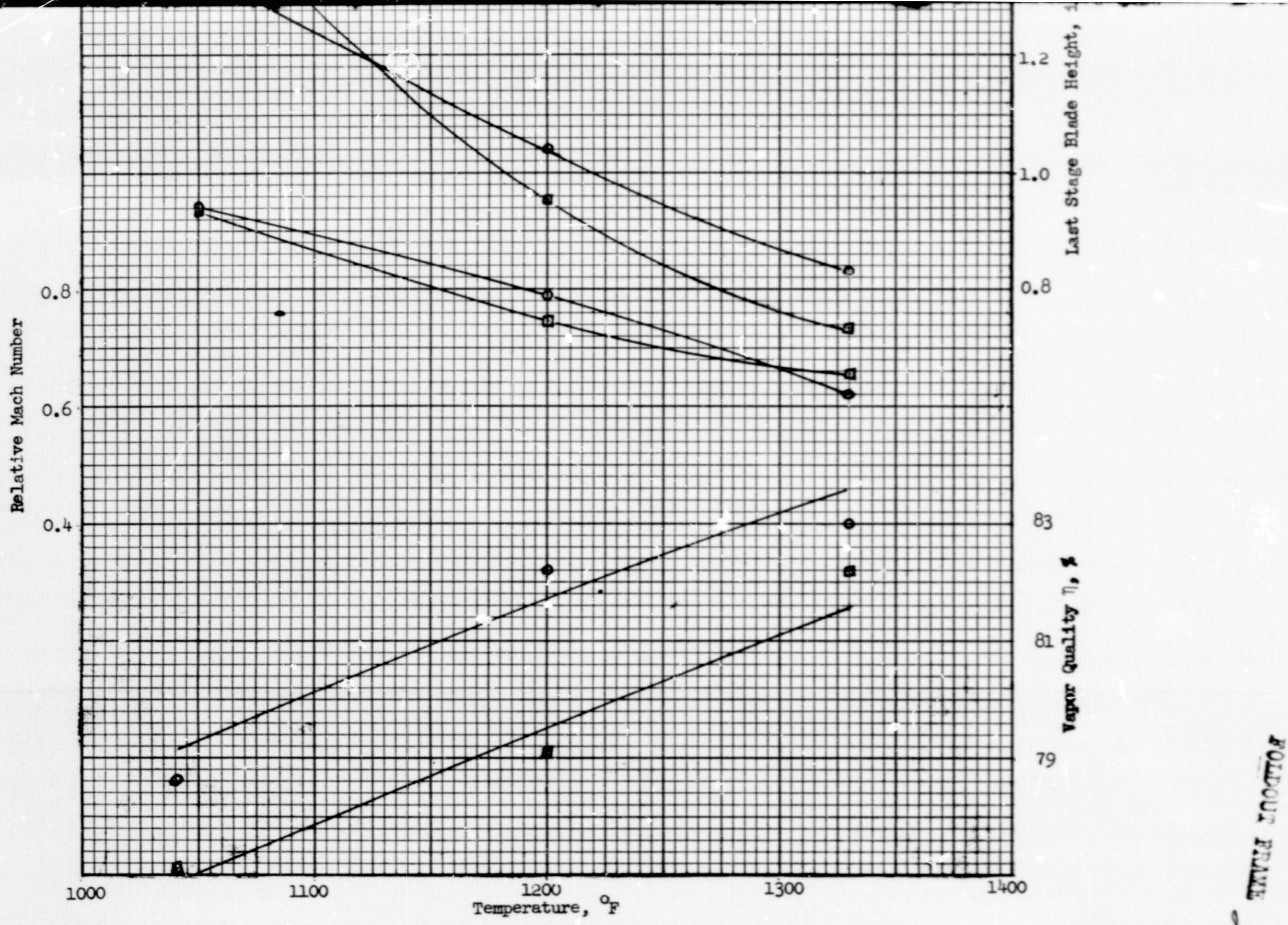


Fig. 17. Effects of Condenser Temperature on a Series of 5-Stage Turbines Supplied With Vapor at 2150°F With Allowances for Regenerative Feed Heating and Aerodynamic, Moisture Churning, and Seal Leakage Losses.

FOLDOUT FRAME 2

ORNL DWG. 68-12591

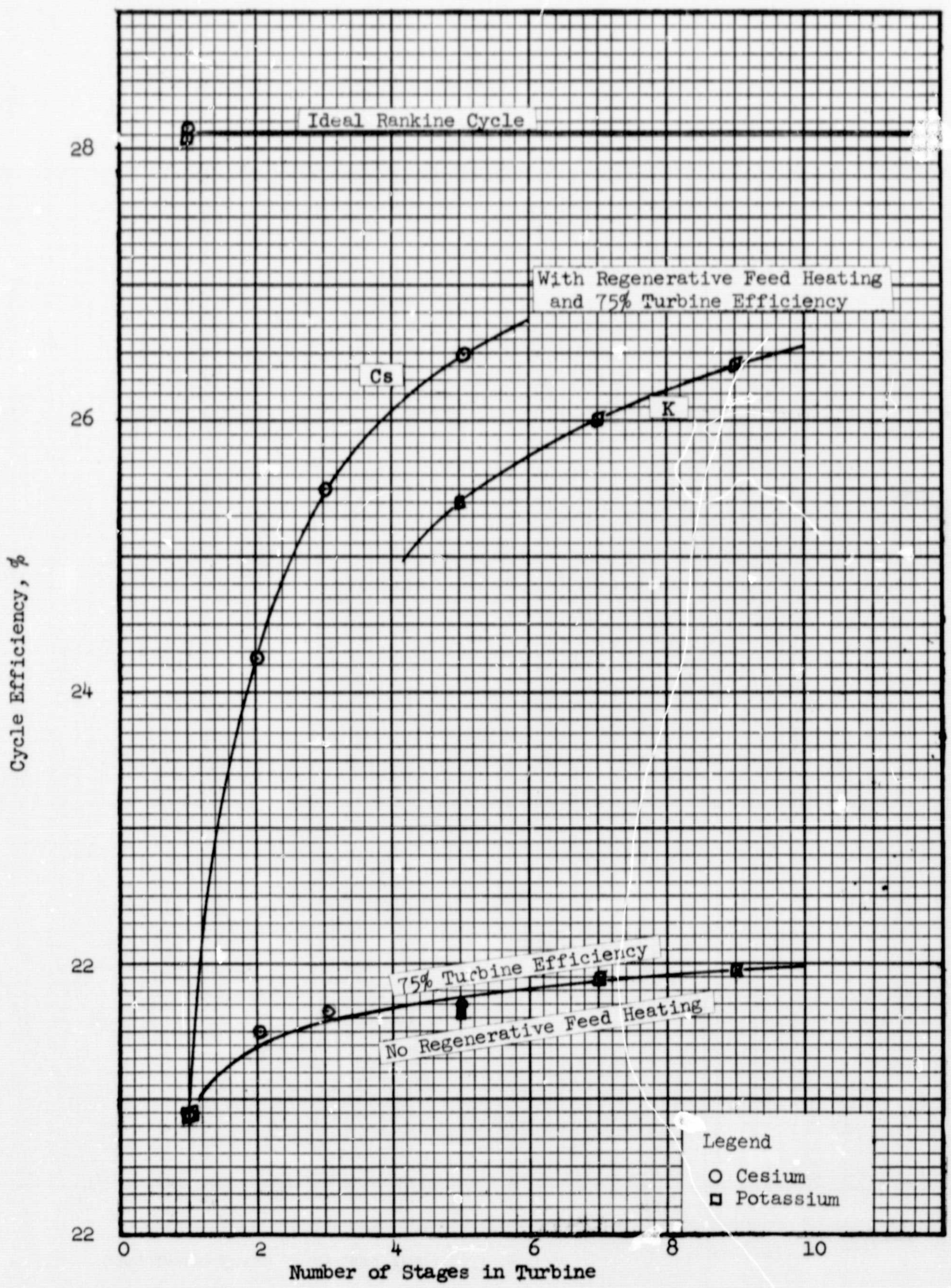


Fig. 18. Effects of Regenerative Feed Heating on the Thermodynamic Cycle Efficiency Assuming a Turbine Efficiency of 75%, Bleed-off Between Each Set of Adjacent Stages, and a Heating Effectiveness of 0.80 for the Regenerative Feed Heater. (T_{in} = 2150°F, T_{out} = 1330°F)

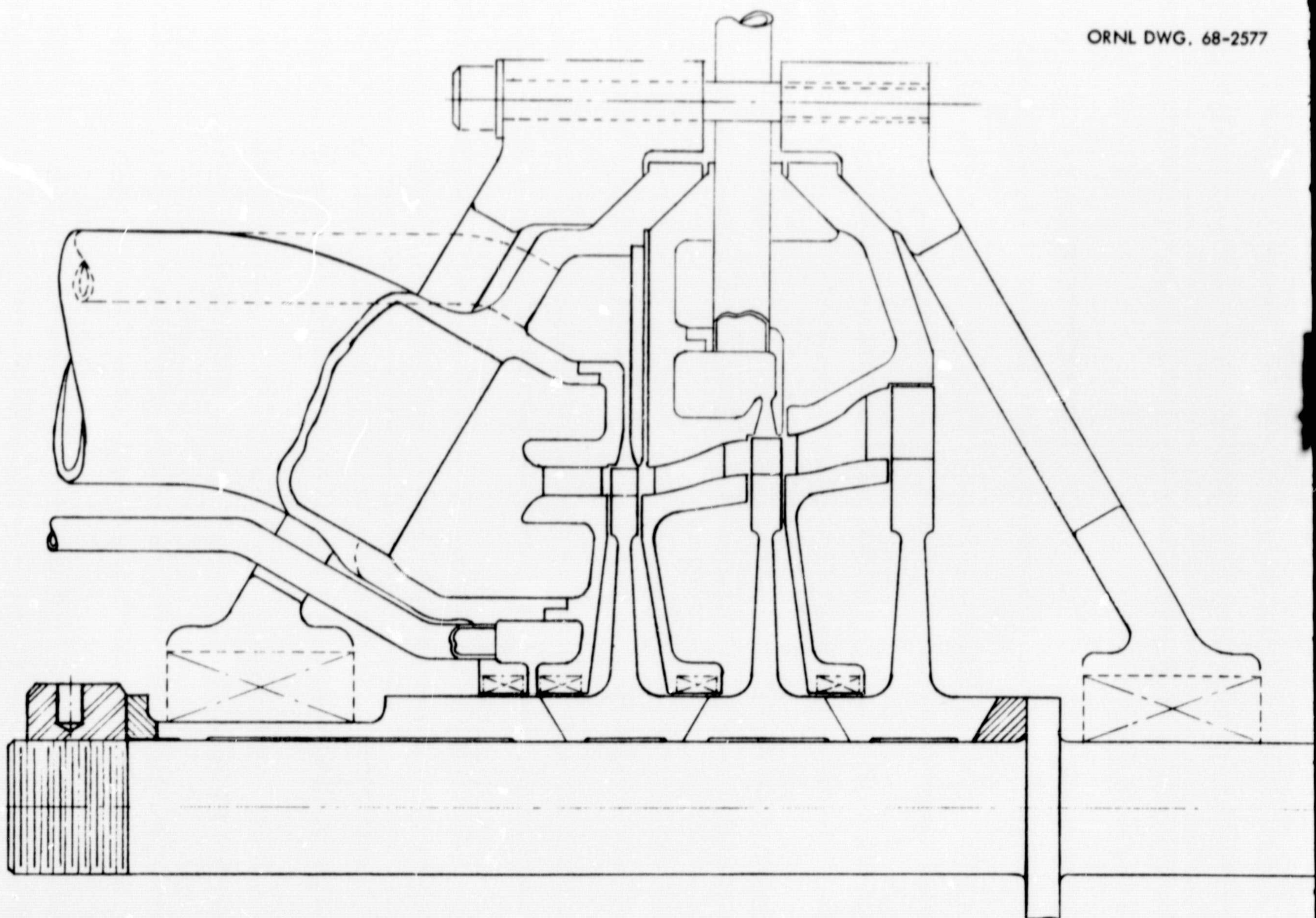


Fig. 19. Reference Design Layout for the Three-Stage, Four-Bearing Cesium Vapor Turbine.

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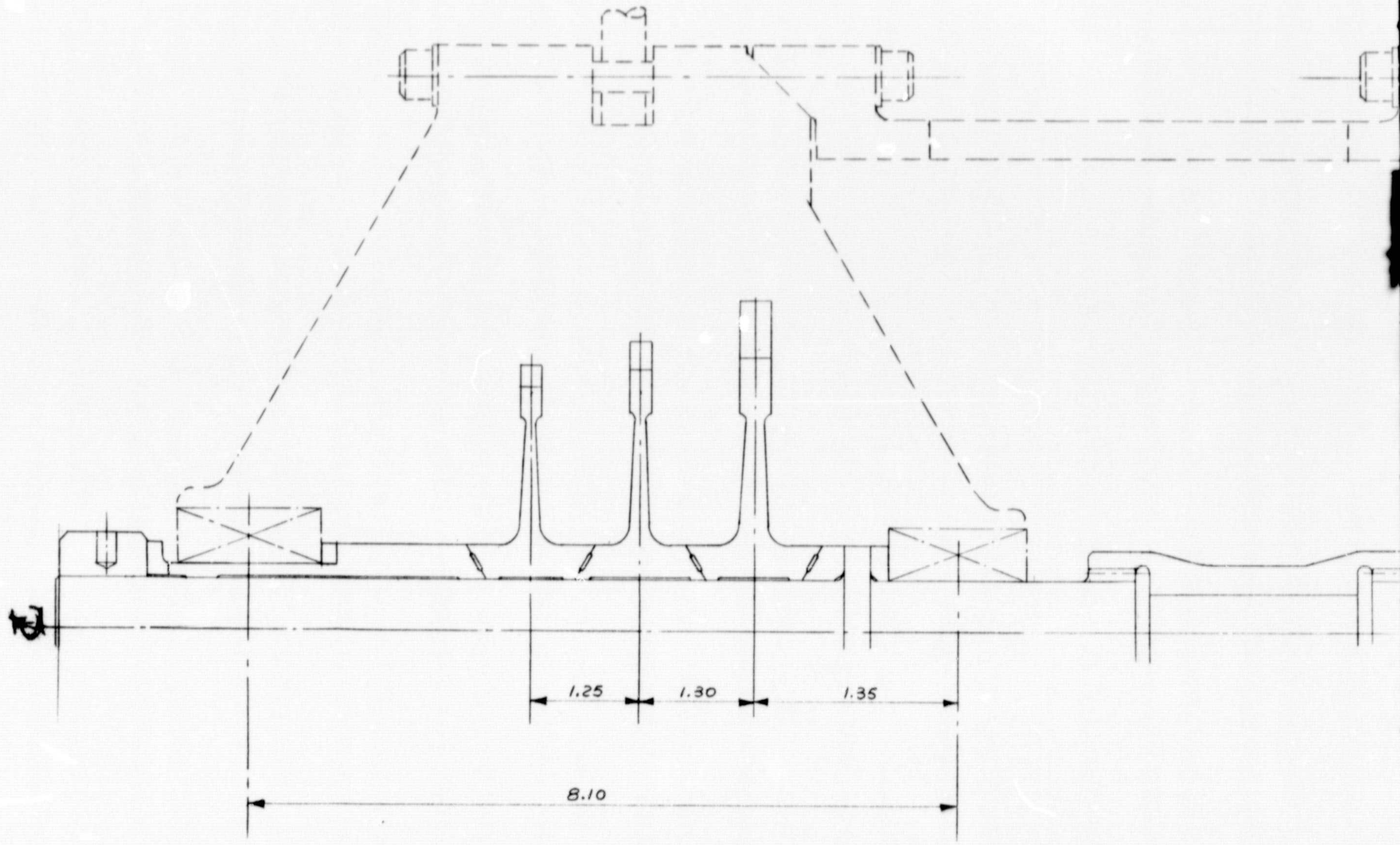

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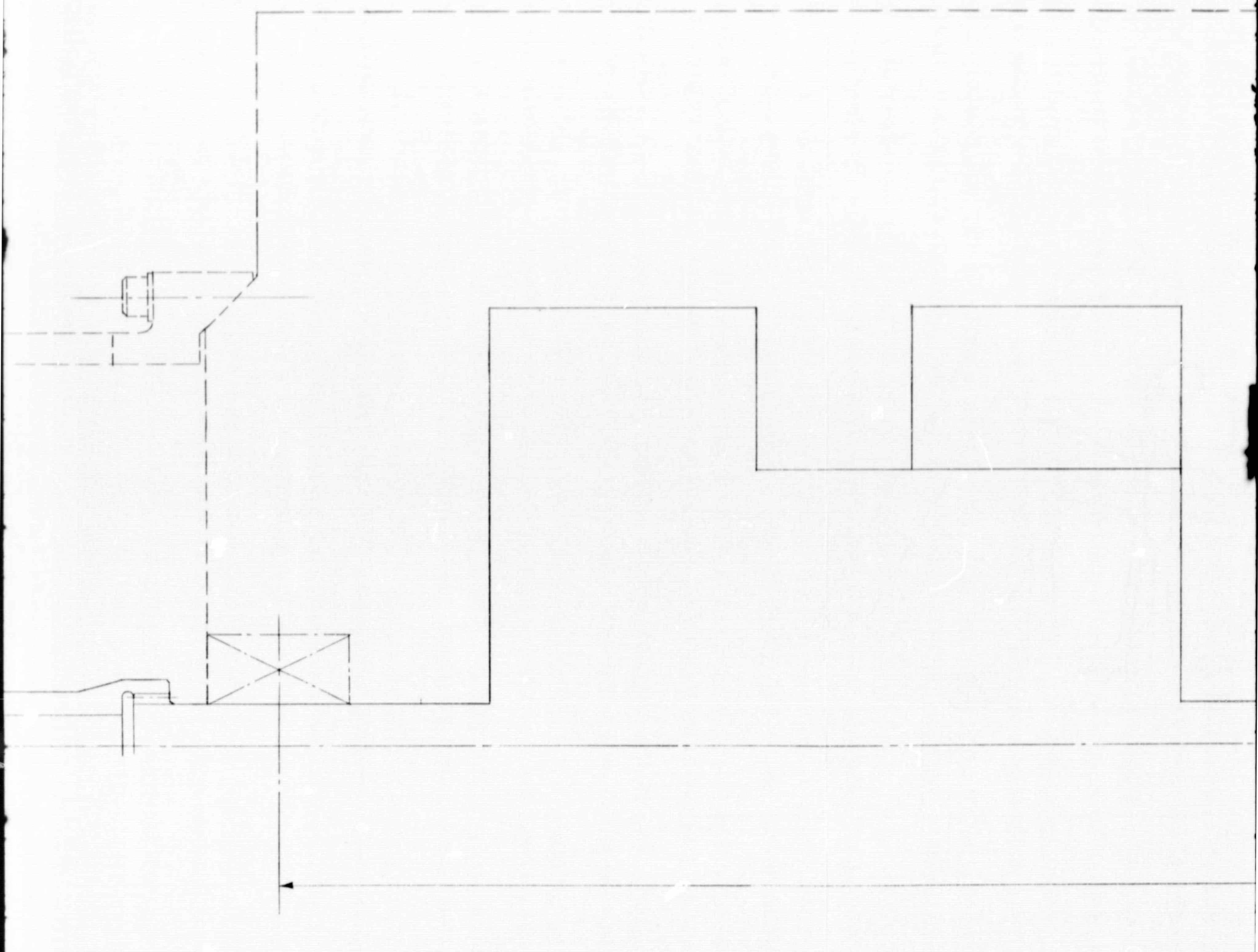

Fig. 20. Rotor Proportio
Vapor Turbine Reference Design

FOLDOUT FRAME 8

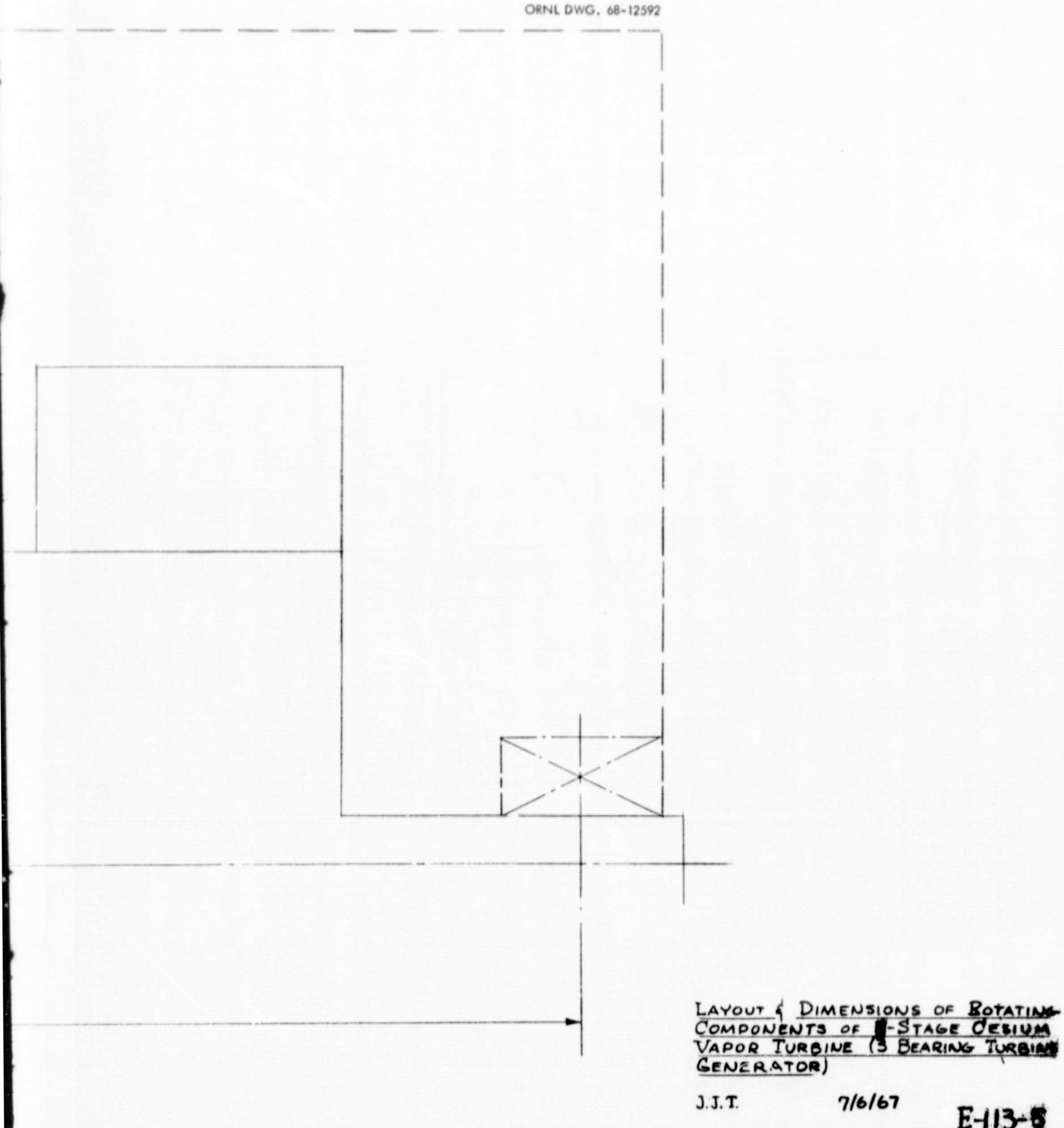

Fig. 20. Rotor Proportions for the Three-Stage, Four-Bearing, Cesium Vapor Turbine Reference Design of Fig. 19.

ORNL DWG. 68-12593

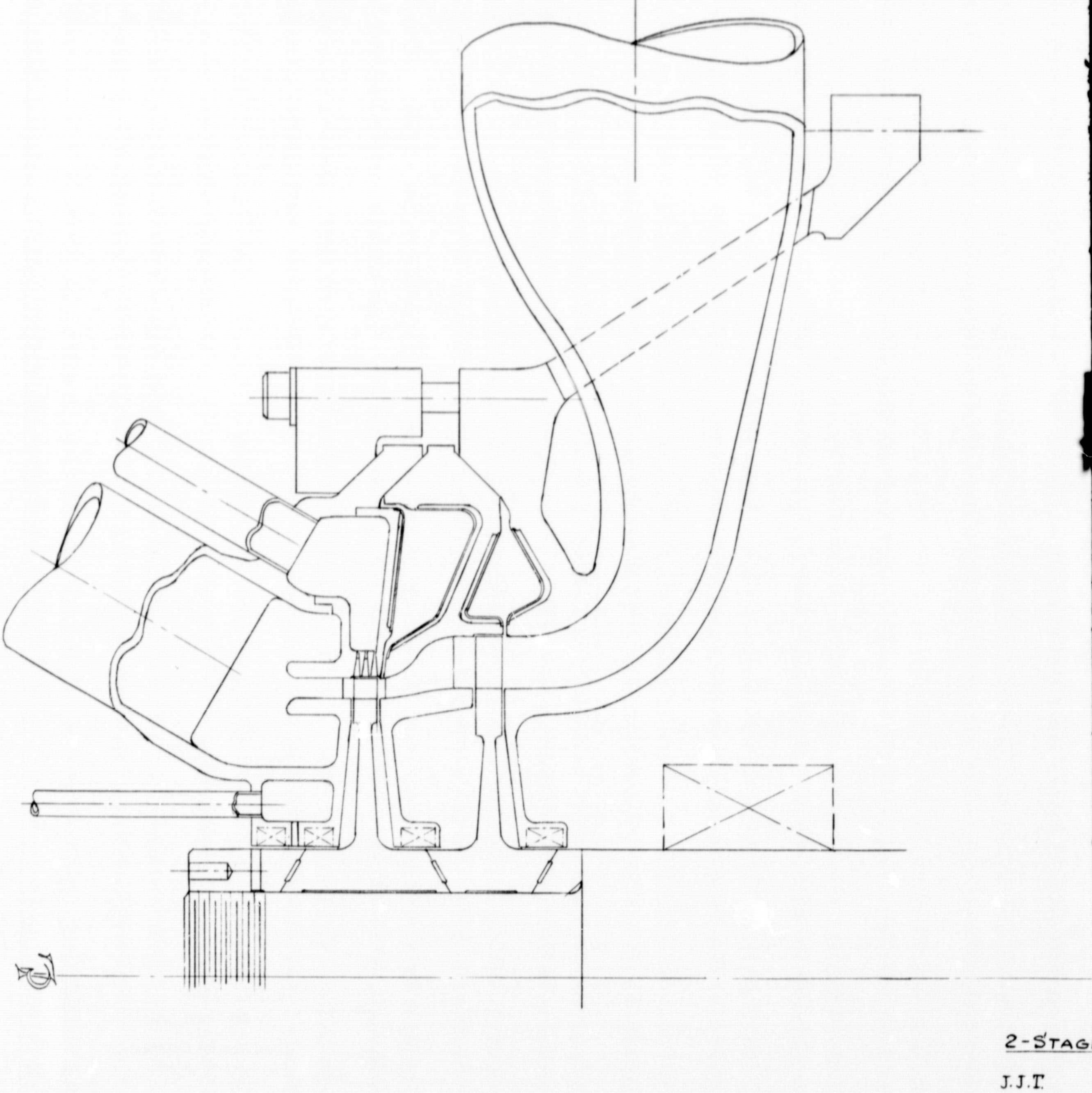

Fig. 21. Reference Design Layout for the Two-Stage, Two-Bearing Cesium Vapor Turbine.

FOLDOUT FRAME 2

L DWG. 68-12593

2-STAGE CESIUM VAPOR TURBINE

J.J.T. 7/14/67

C-113-9

-Stage, Two-Bearing

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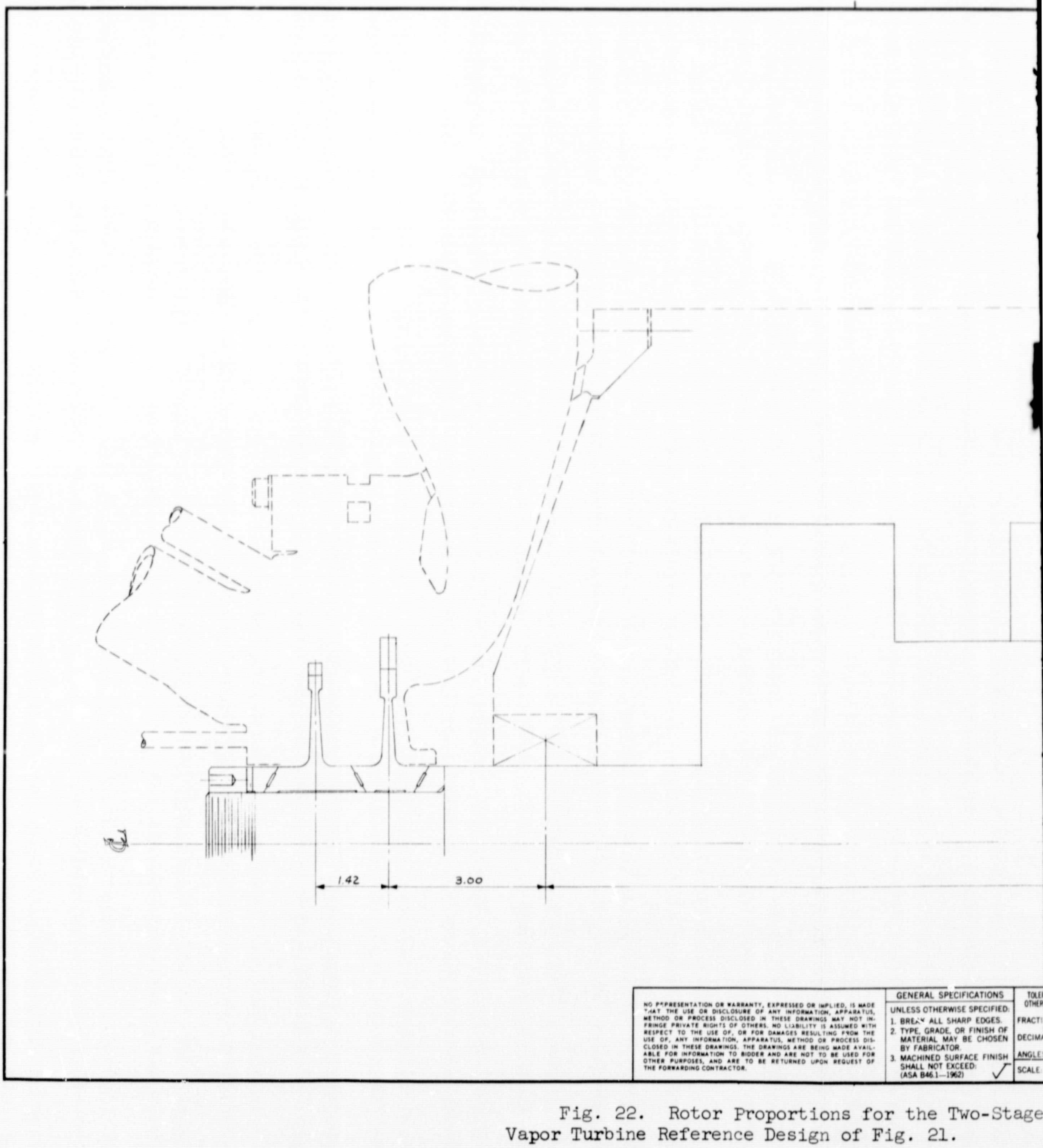
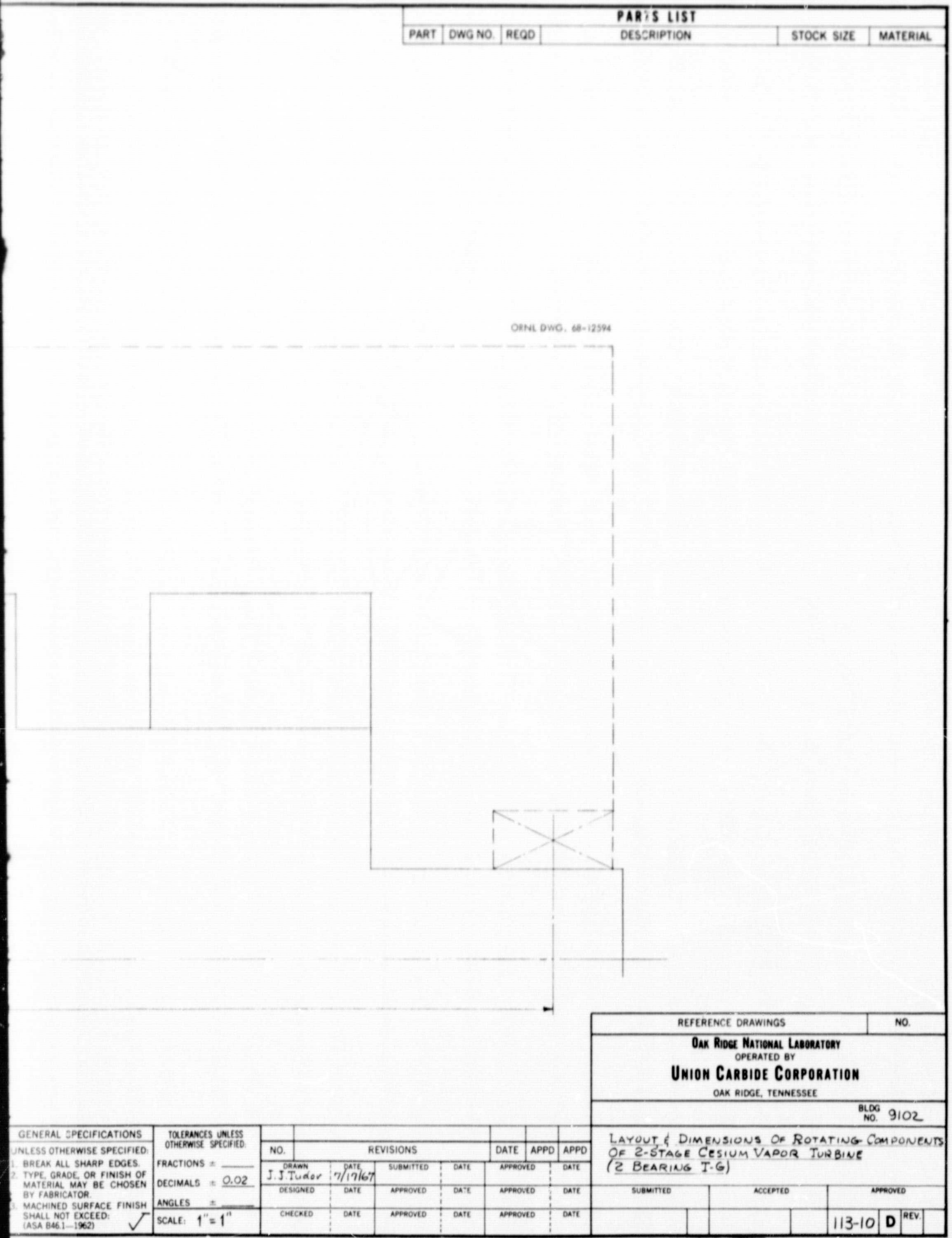


Fig. 22. Rotor Proportions for the Two-Stage Vapor Turbine Reference Design of Fig. 21.



the Two-Stage, Two-Bearing, Cesium
g. 21.

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ORNL DWG. 68

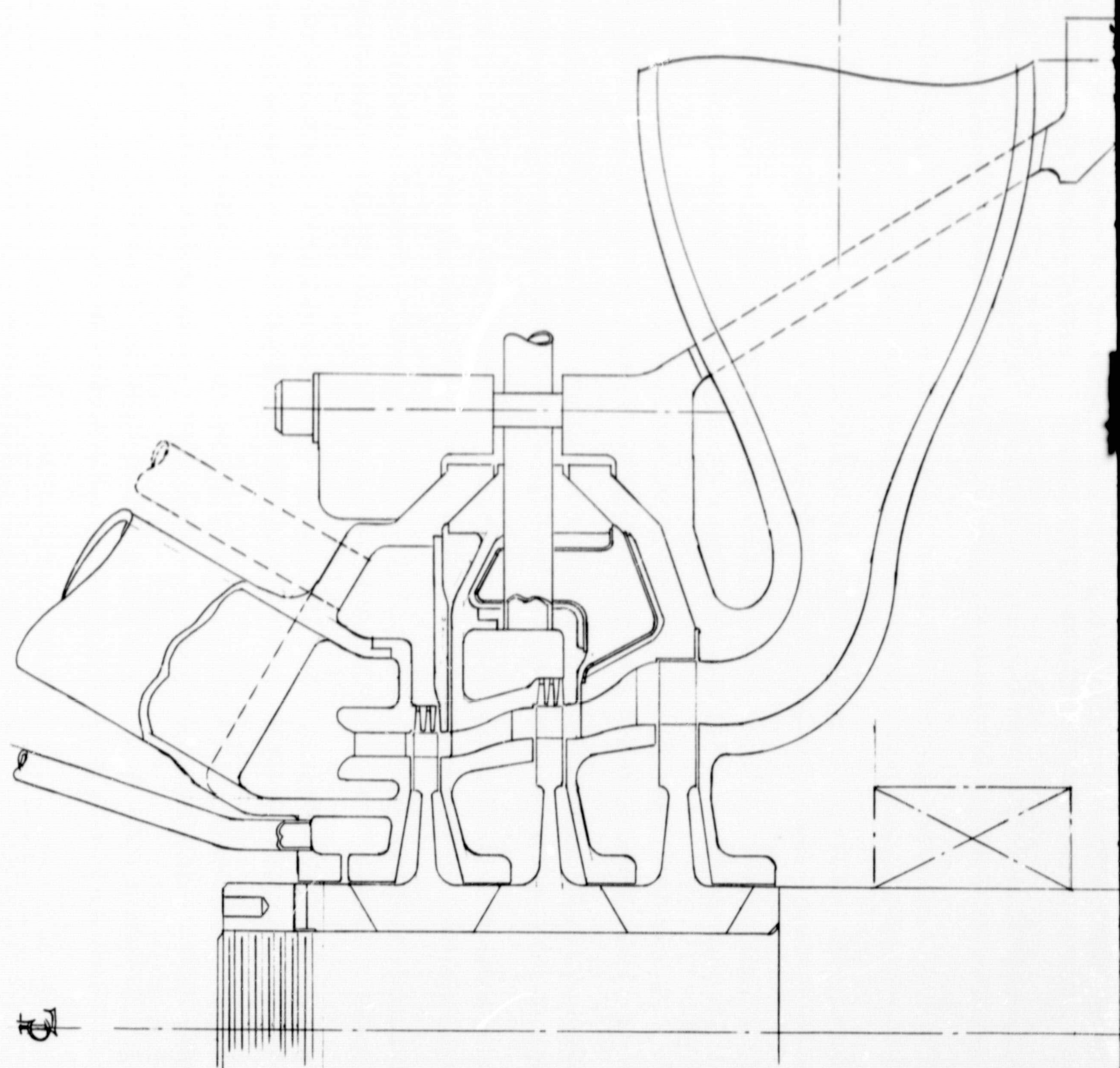

Fig. 23. Reference Design Layout for the Thr
Cesium Vapor Turbine.

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ORNL DWG. 68-12595

3-STAGE CESIUM VAPOR TURBINE
(2 BEARING TURBINE-GENERATOR)

J. J. T. 7/6/67 C-113-1

for the Three-Stage, Two-Bearing,

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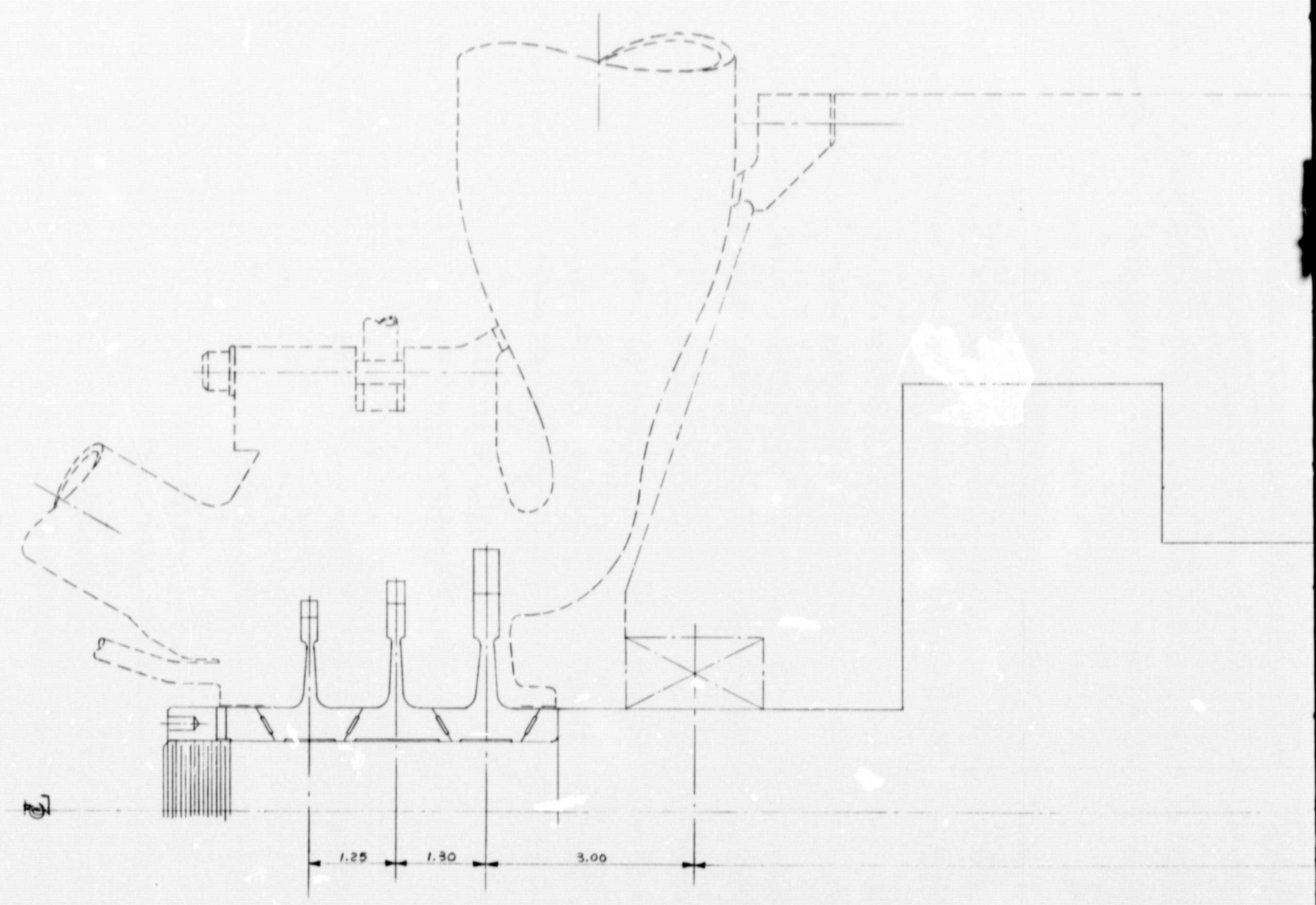

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3. MACHINED SURFACE FINISH SHALL NOT EXCEED: √ (ASA B46.1—1962)

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SCALE:

Fig. 24. Rotor Proportions for the Three-Stag
Vapor Turbine Reference Design of Fig. 23.

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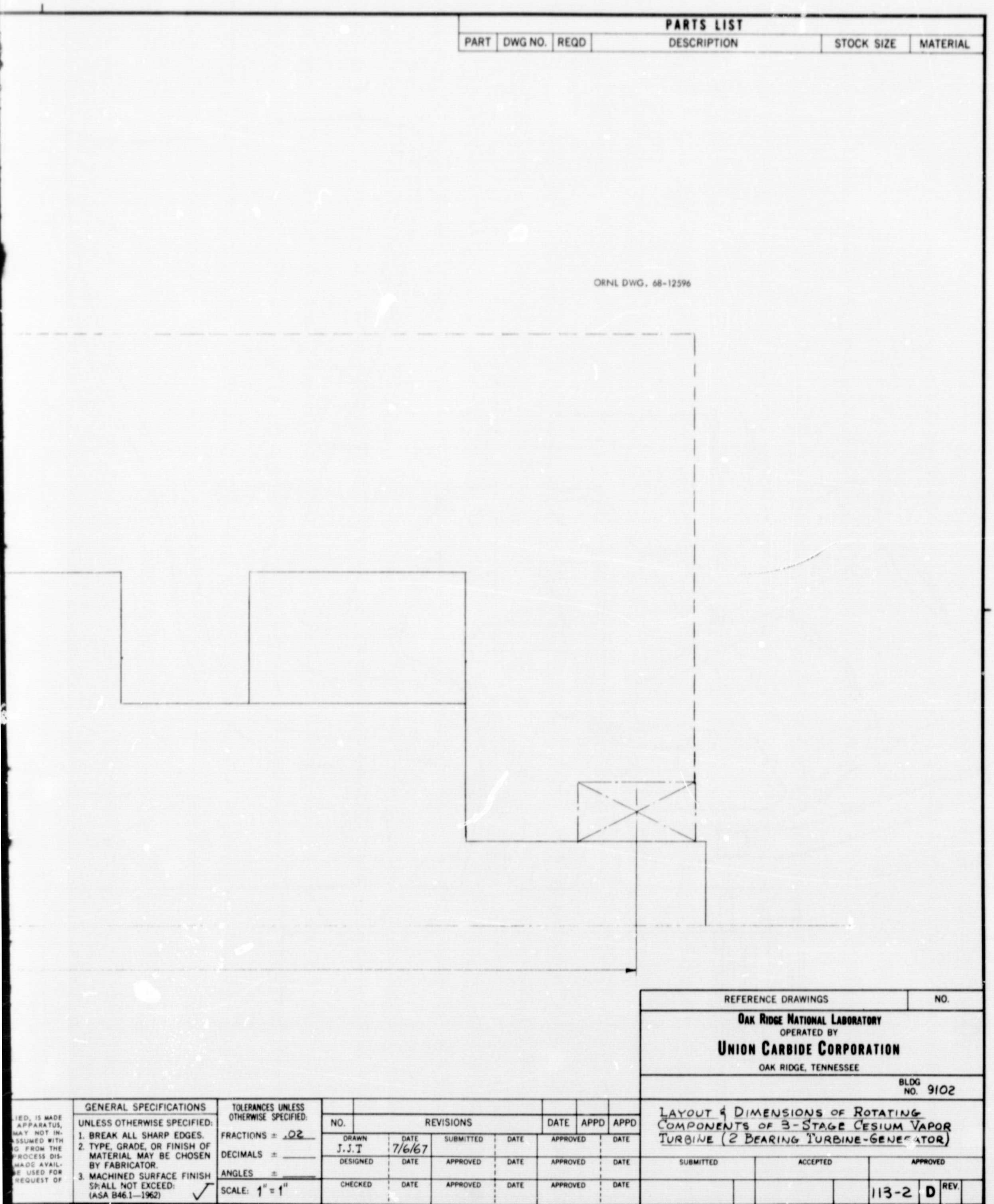


s for the Three-Stage, Two-Bearing, Cesium
of Fig. 23.

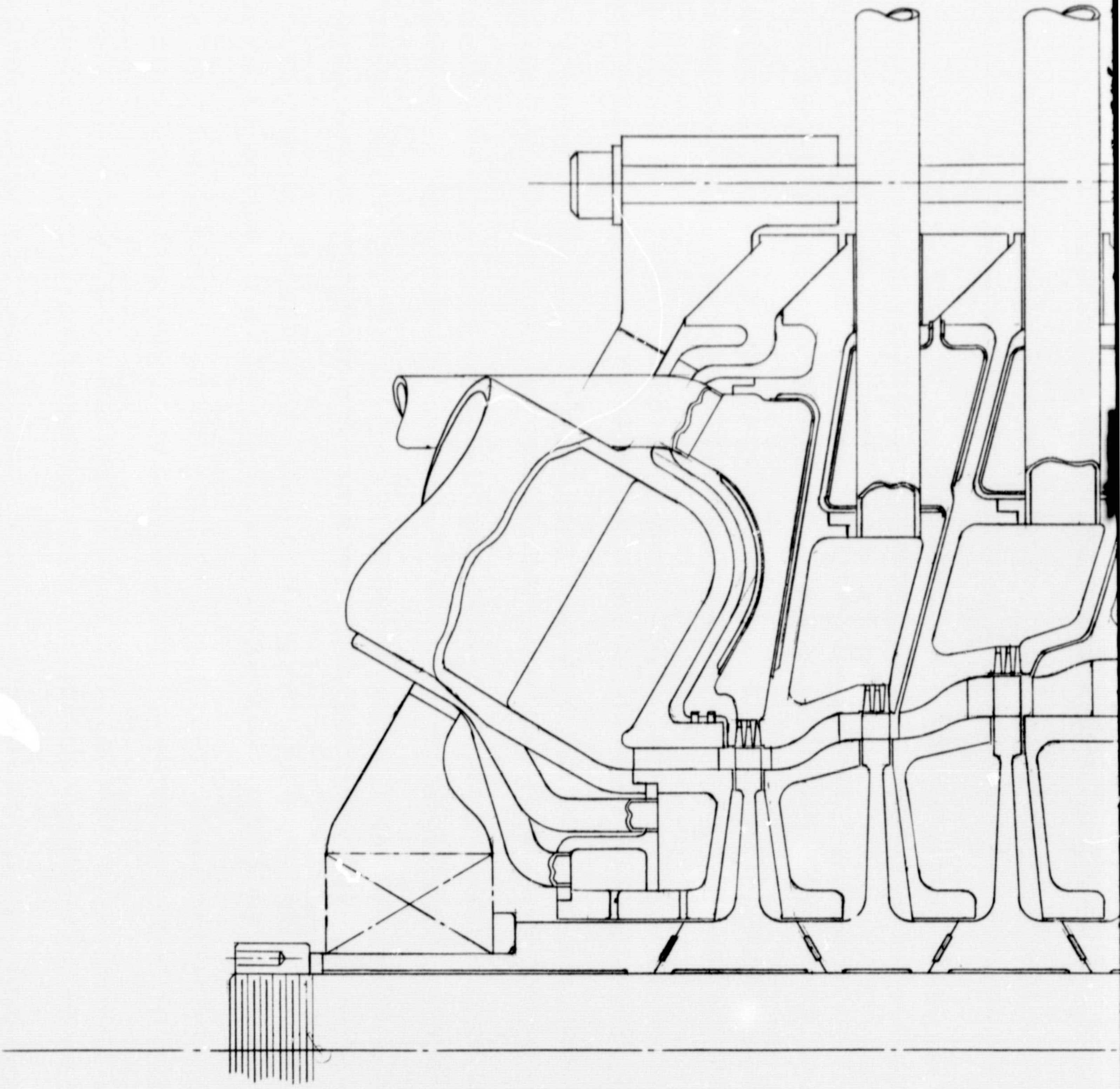
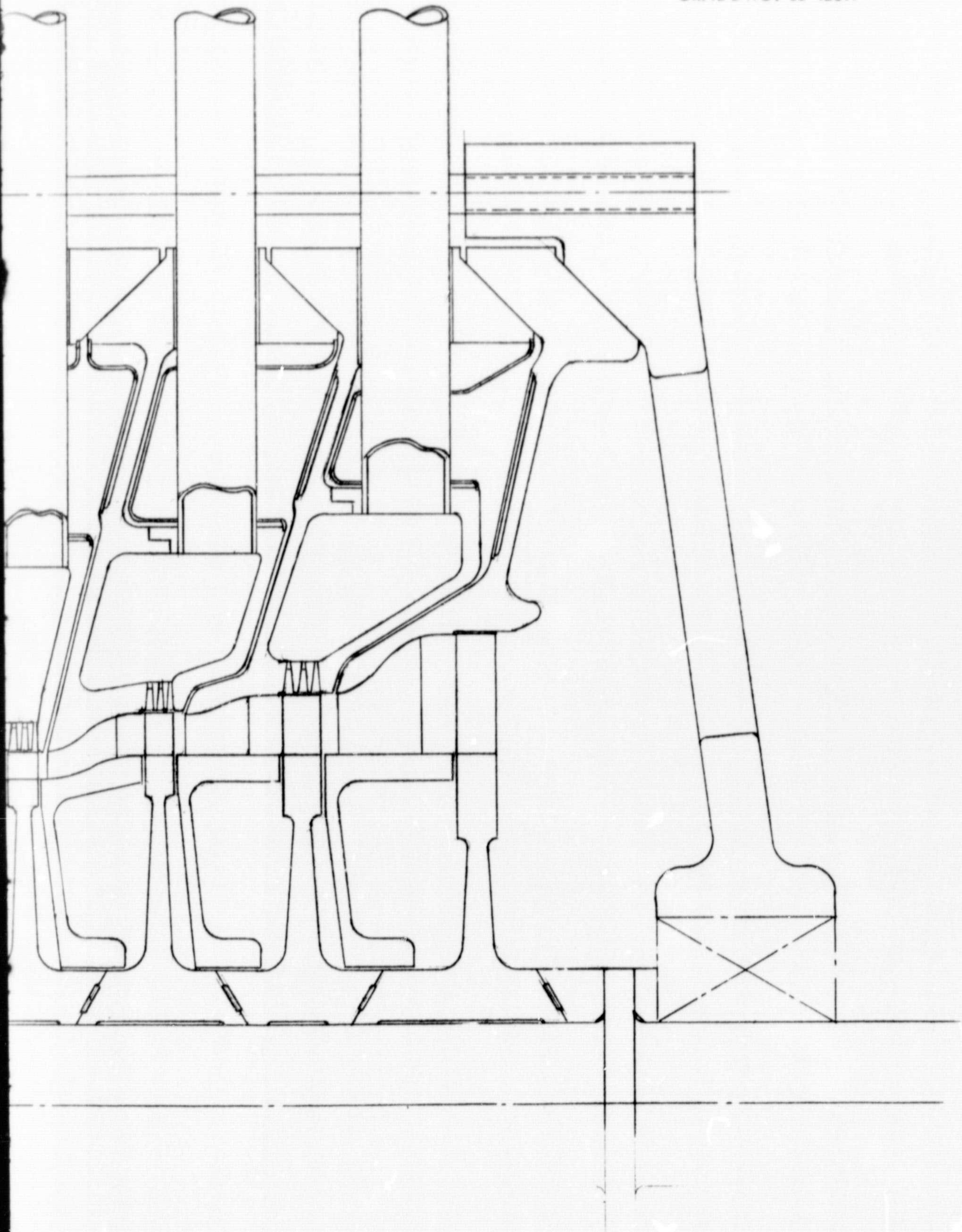


Fig. 25. Referen e Design Layout fo
Potassium Vapor Turbine.

2

ORNL DWG. 68-12597

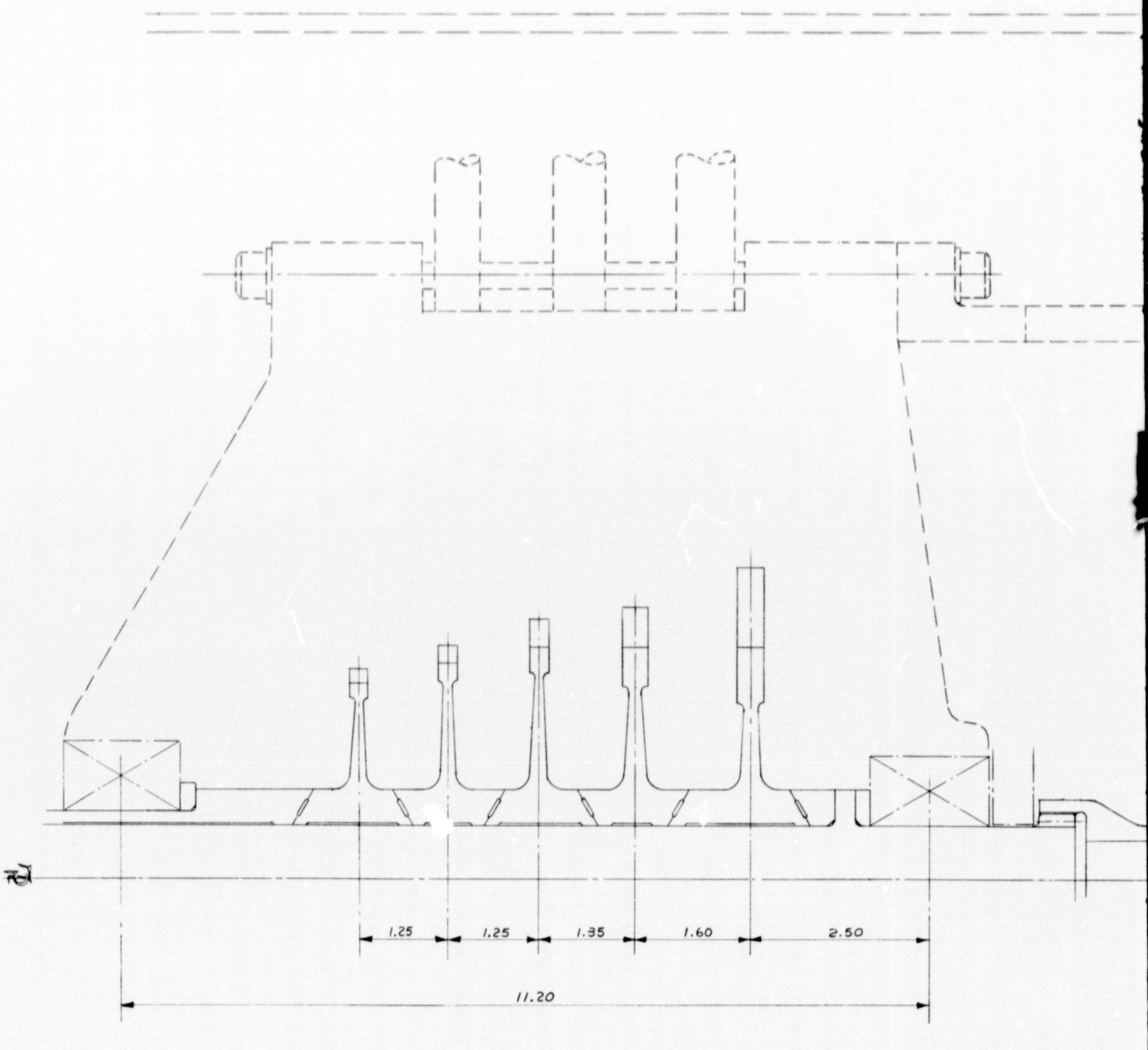


5-STAGE POTASSIUM VAPOR TURBINE

ce Design Layout for the Five-Stage, Four-Bearing
e.

1

FOLDOUT FRAME 1



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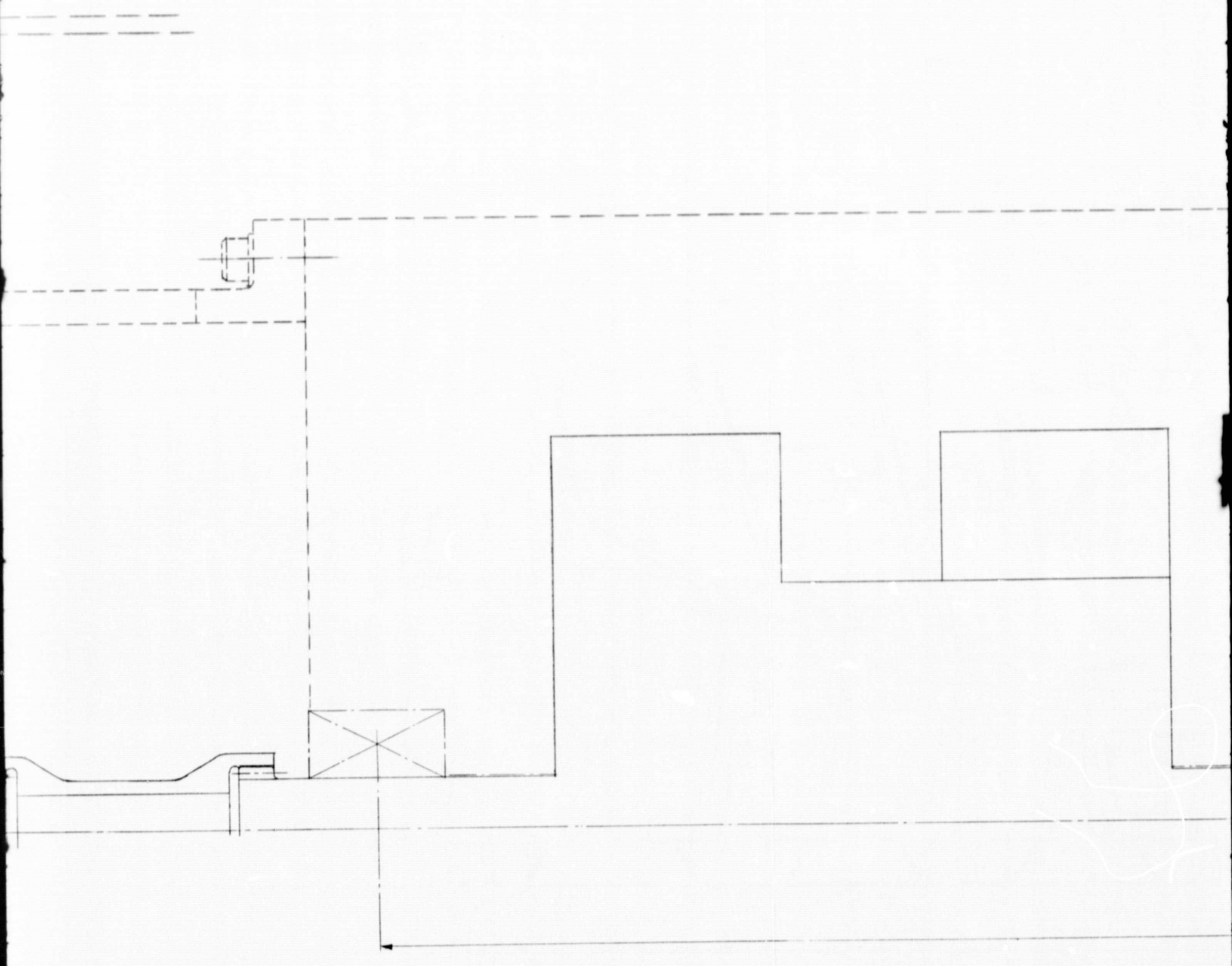

Fig. 26. Rotor Proportion
Vapor Turbine Reference Design

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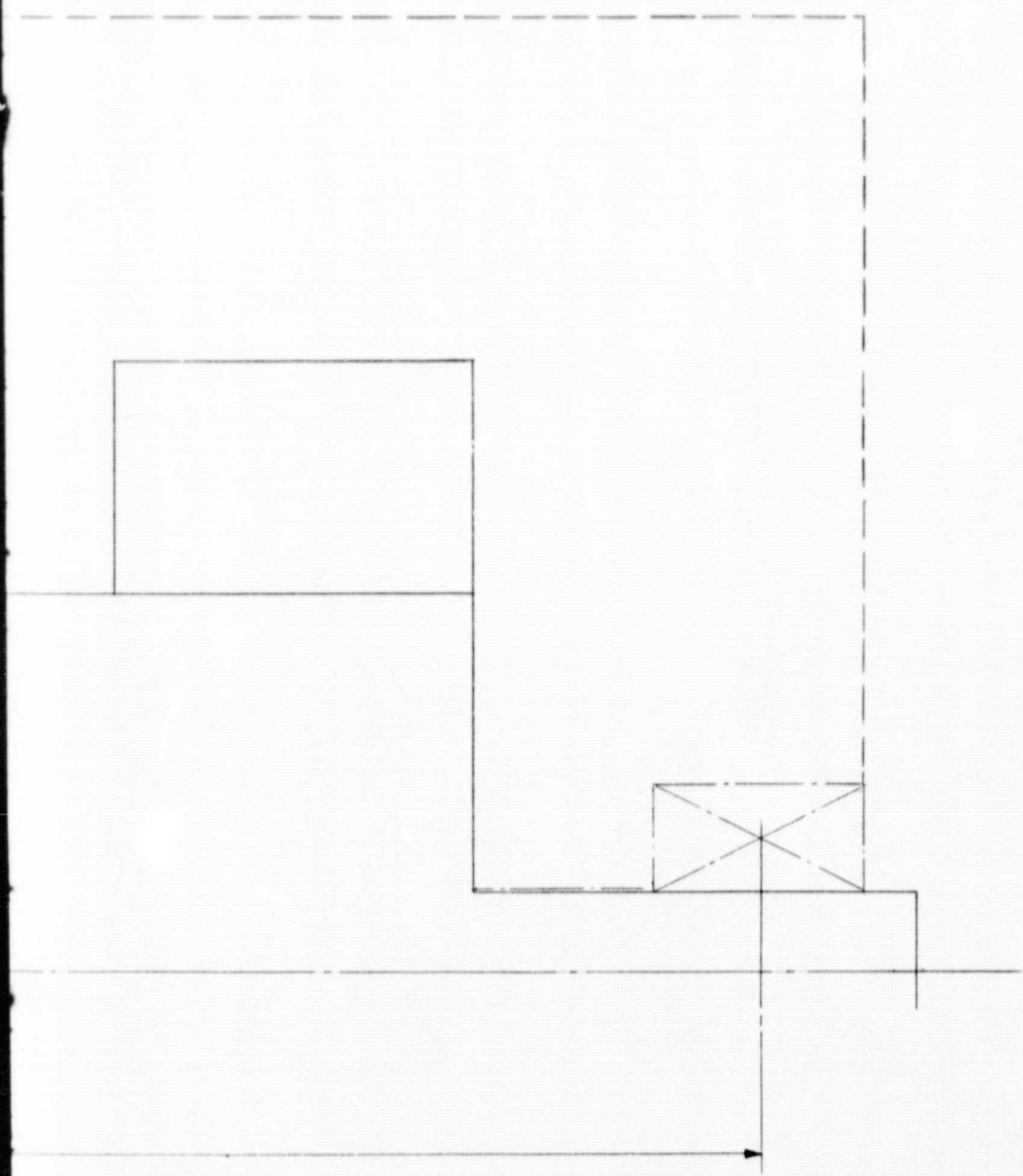
ORNL DWG. 68-12598



LAYOUT & DIMENSIONS OF ROTATING COMPONENENTS OF 5-STAGE POTASSIUM VAPOR TURBINE (4 BEARING TURBINE-GENERATOR)

J.J.T. 7/6/67 E-113-6

Fig. 26. Rotor Proportions for the Five-Stage, Four-Bearing Potassium Vapor Turbine Reference Design of Fig. 25.

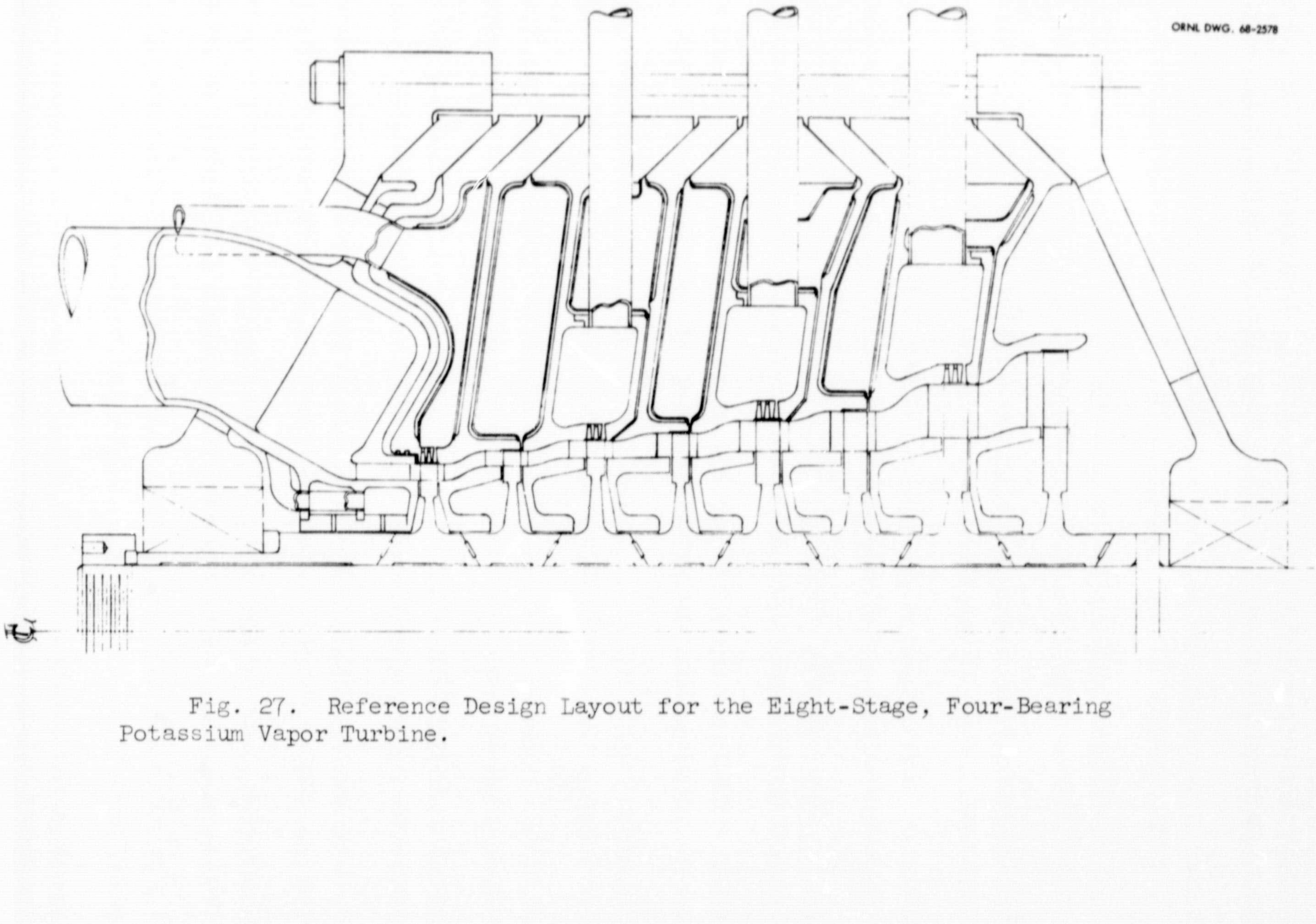


Fig. 27. Reference Design Layout for the Eight-Stage, Four-Bearing Potassium Vapor Turbine.

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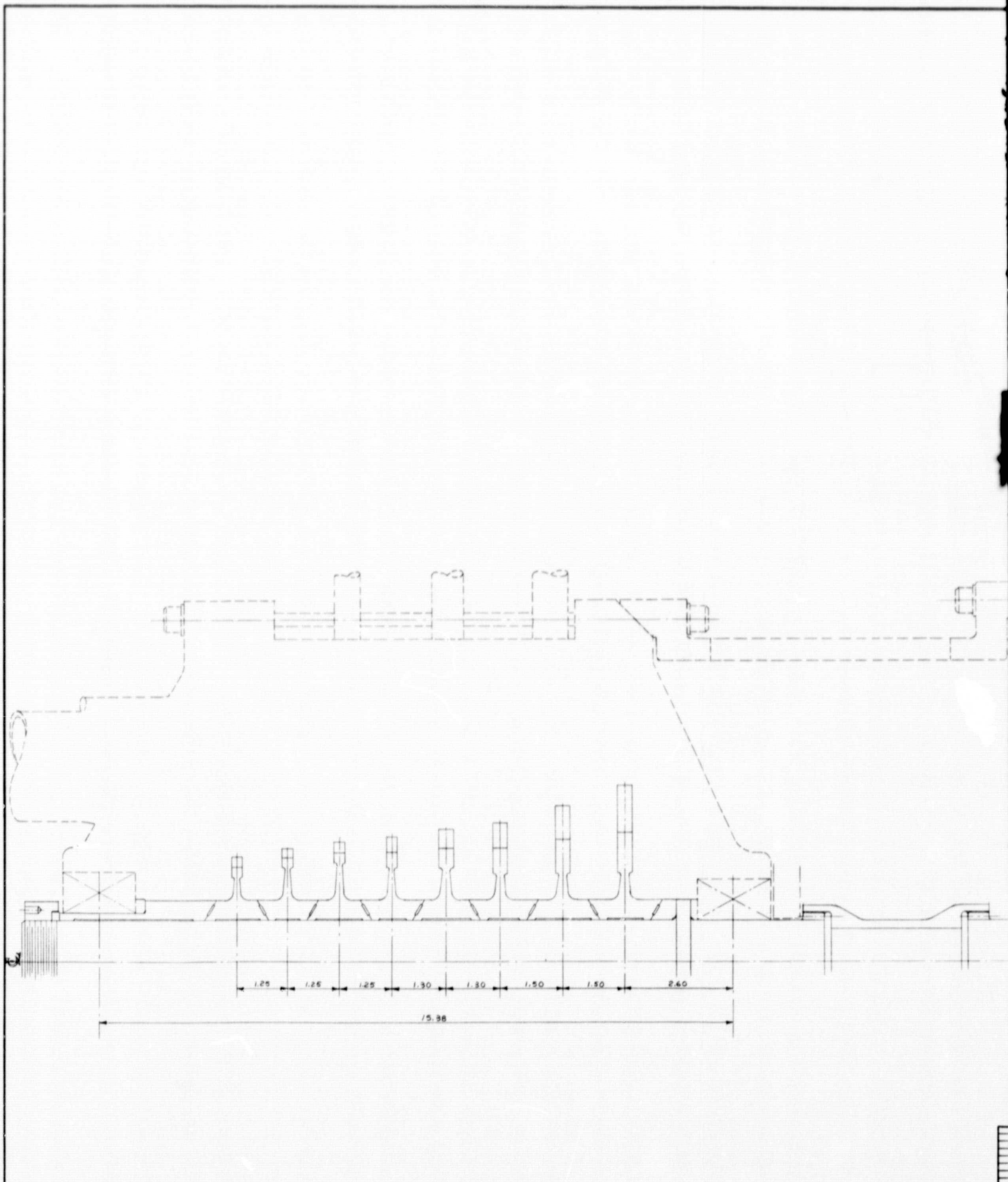

Fig. 28. Rotor Proportions for the Eight-St
Vapor Turbine Reference Design of Fig. 27.

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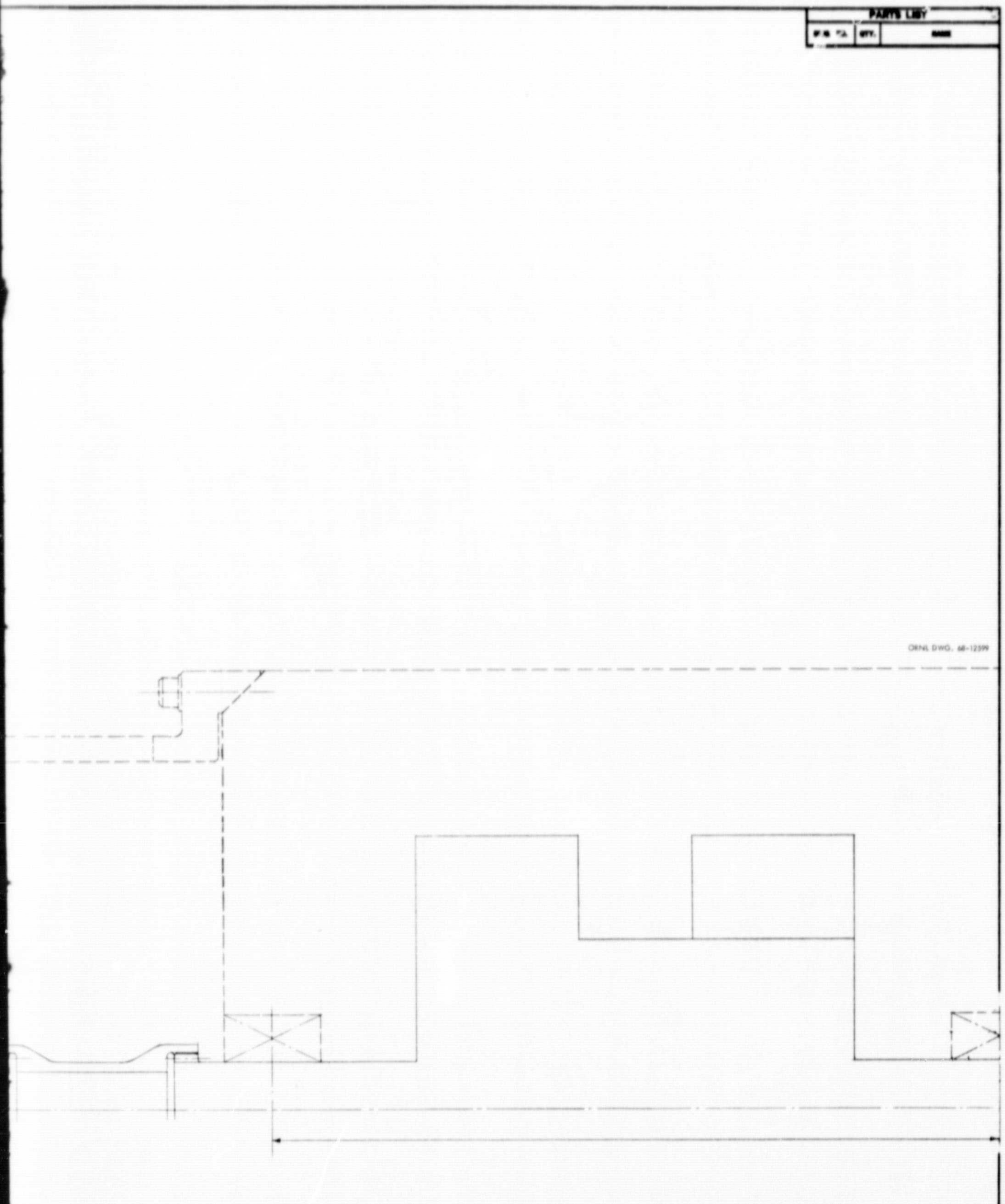


for the Eight-Stage, Four-Bearing Potassium
Fig. 27.

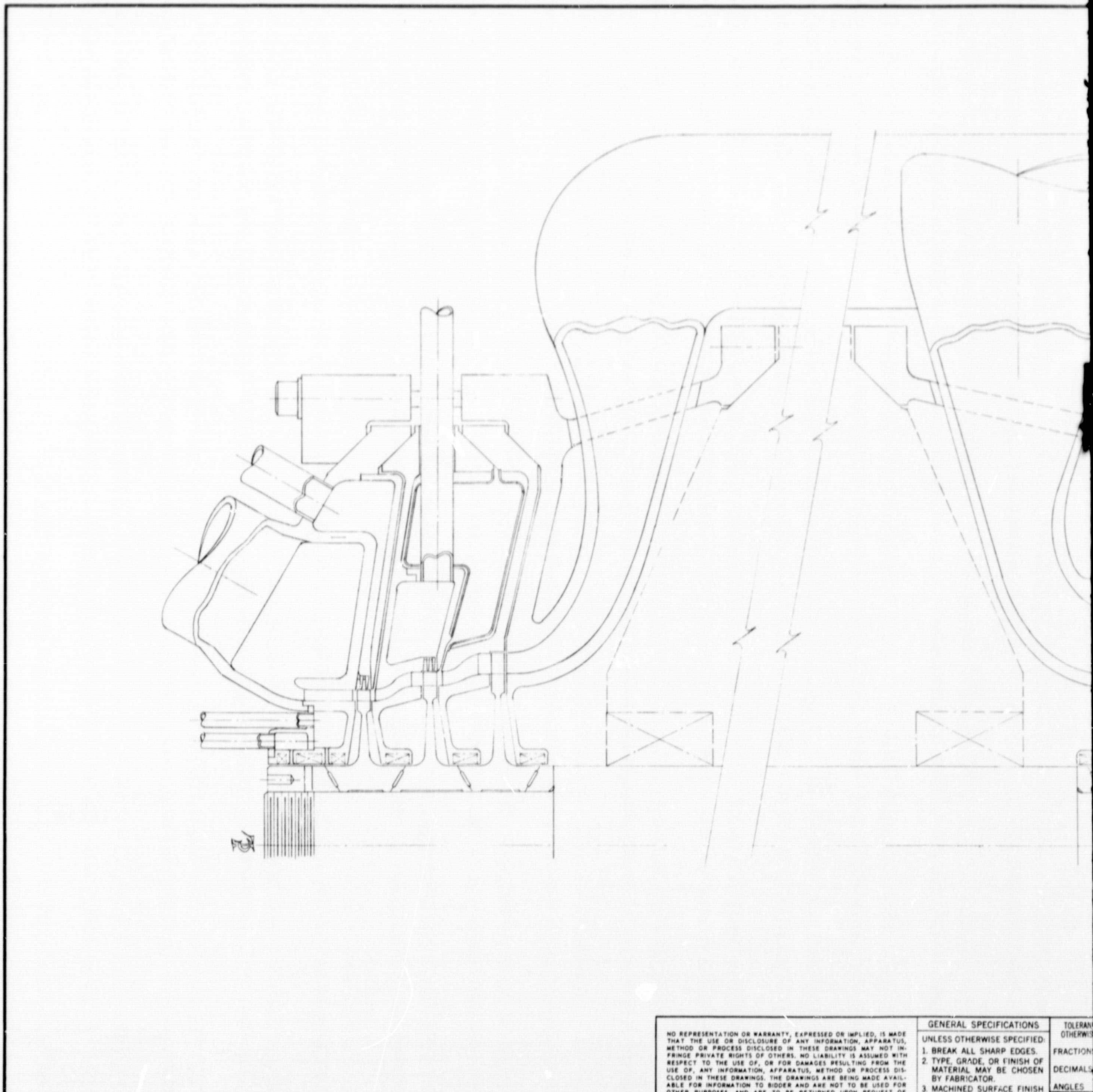


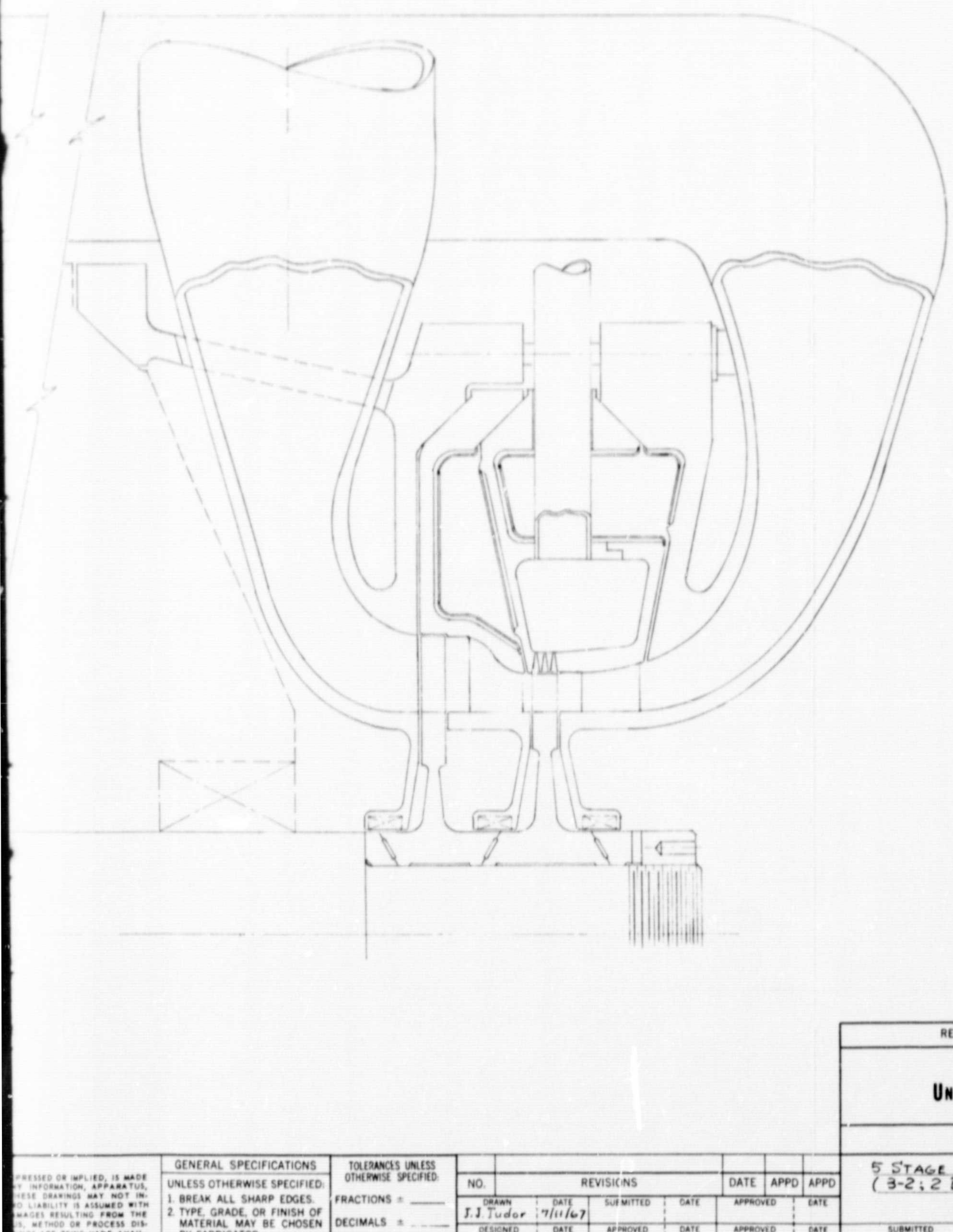
Fig. 29. Reference Design Layout for the Five-Stage, Two-
Potassium Vapor Turbine.

FOLDOUT FRAME 2

PARTS LIST

PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL

ORNL DWG. 68-12600



REFERENCE DRAWINGS	NO.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

BLDG NO. 9102

5 STAGE POTASSIUM VAPOR TURBINE
(3-2; 2 BEARING)

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TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± ____
DECIMALS ± ____
ANGLES ± ____
SCALE: 1" = 1"

NO.	REVISIONS	DATE	APPD	APPD

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE
J. J. Tudor	7/11/67				
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE

SUBMITTED	ACCEPTED	APPROVED
		113-8 D REV.

...ut for the Five-Stage, Two-Bearing

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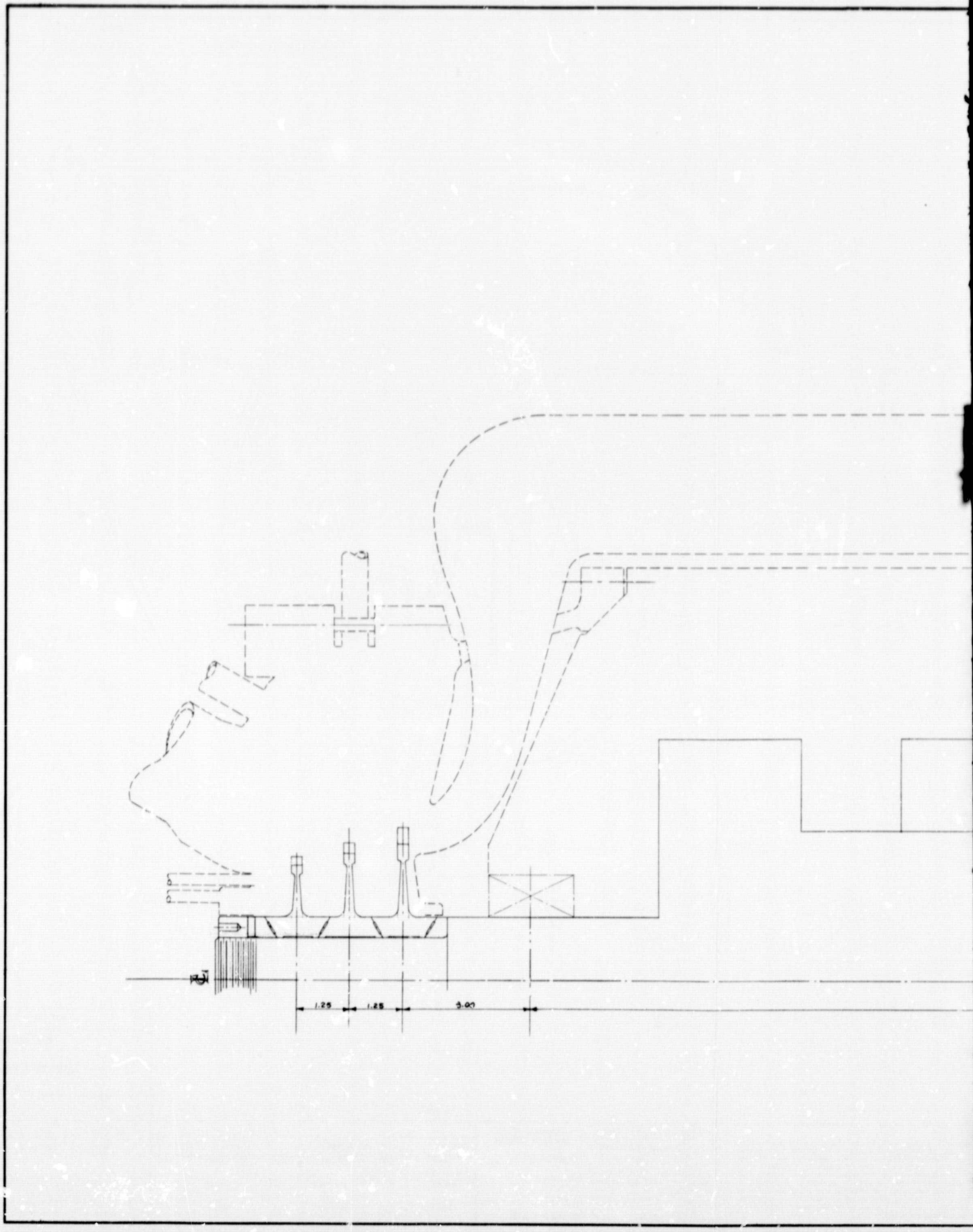

Fig. 30. Rotor Proportions for the Five
Vapor Turbine Reference Design of Fig. 29.

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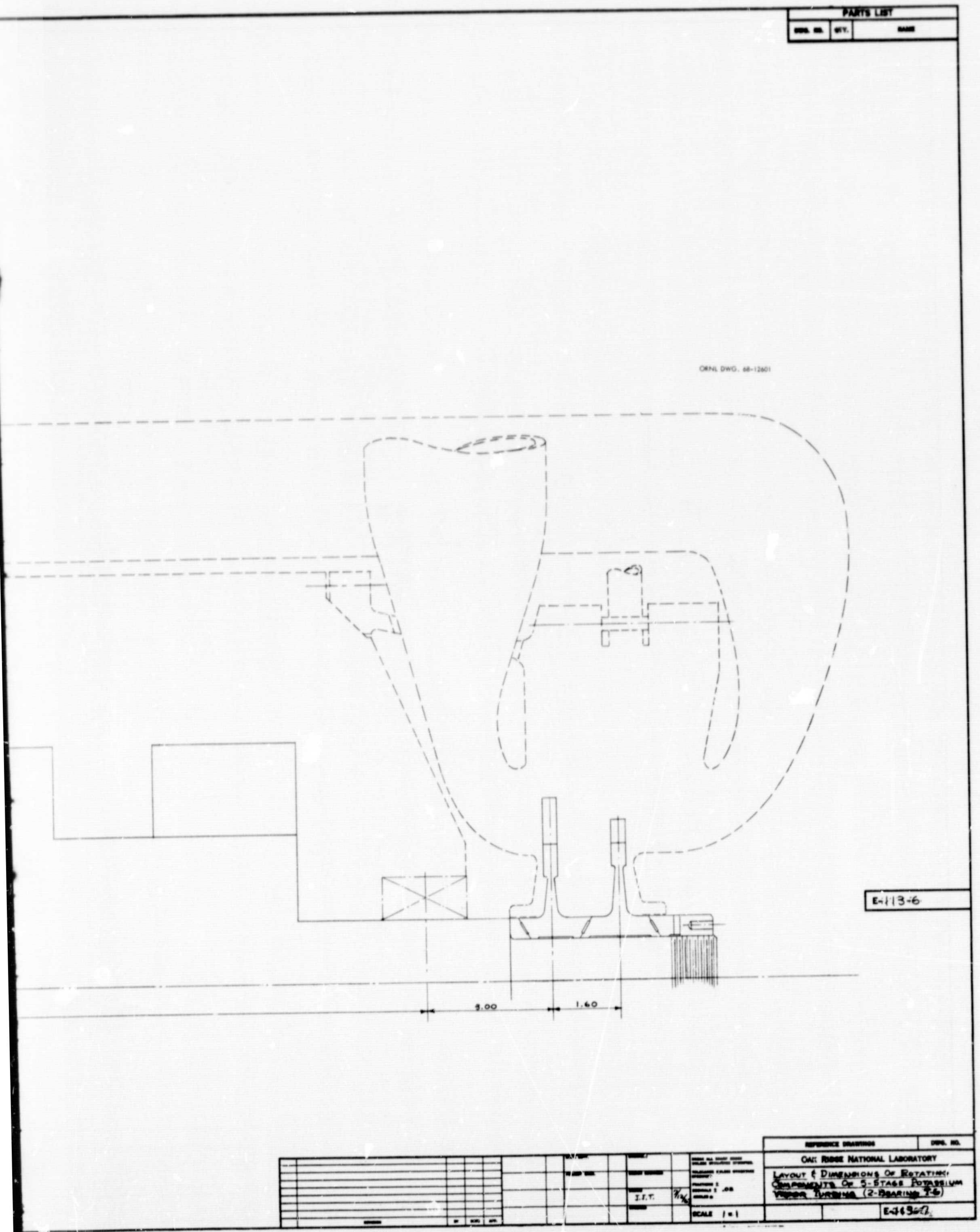


tions for the Five-Stage, Two-Bearing Potassium
ign of Fig. 29.

ORNL DWG. 68-12602

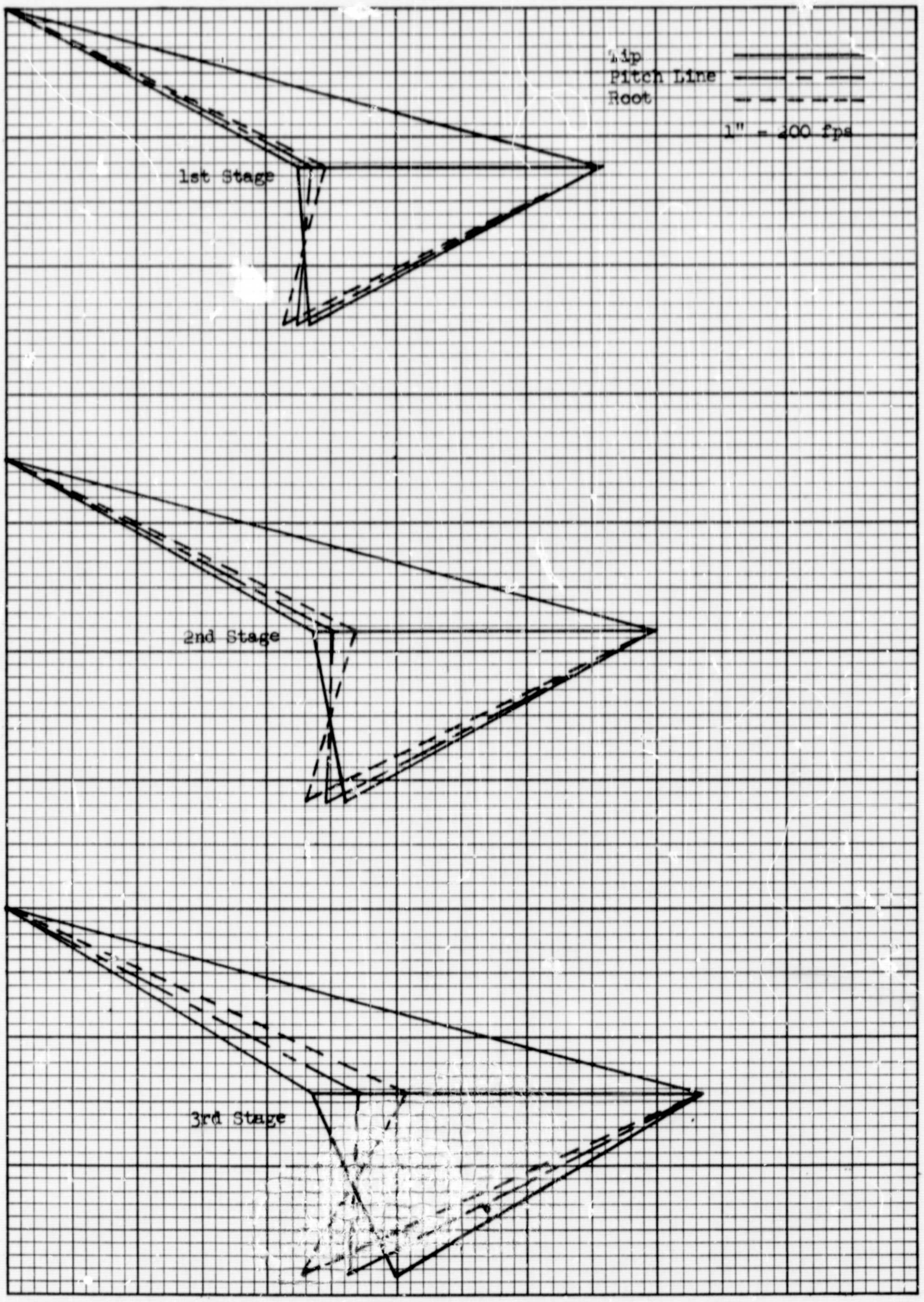


Fig. 31. Velocity Diagrams for the Three-Stage Rotor for the Cesium Turbine of Table 22 and Fig. 19.

ORNL DWG. 68-12603

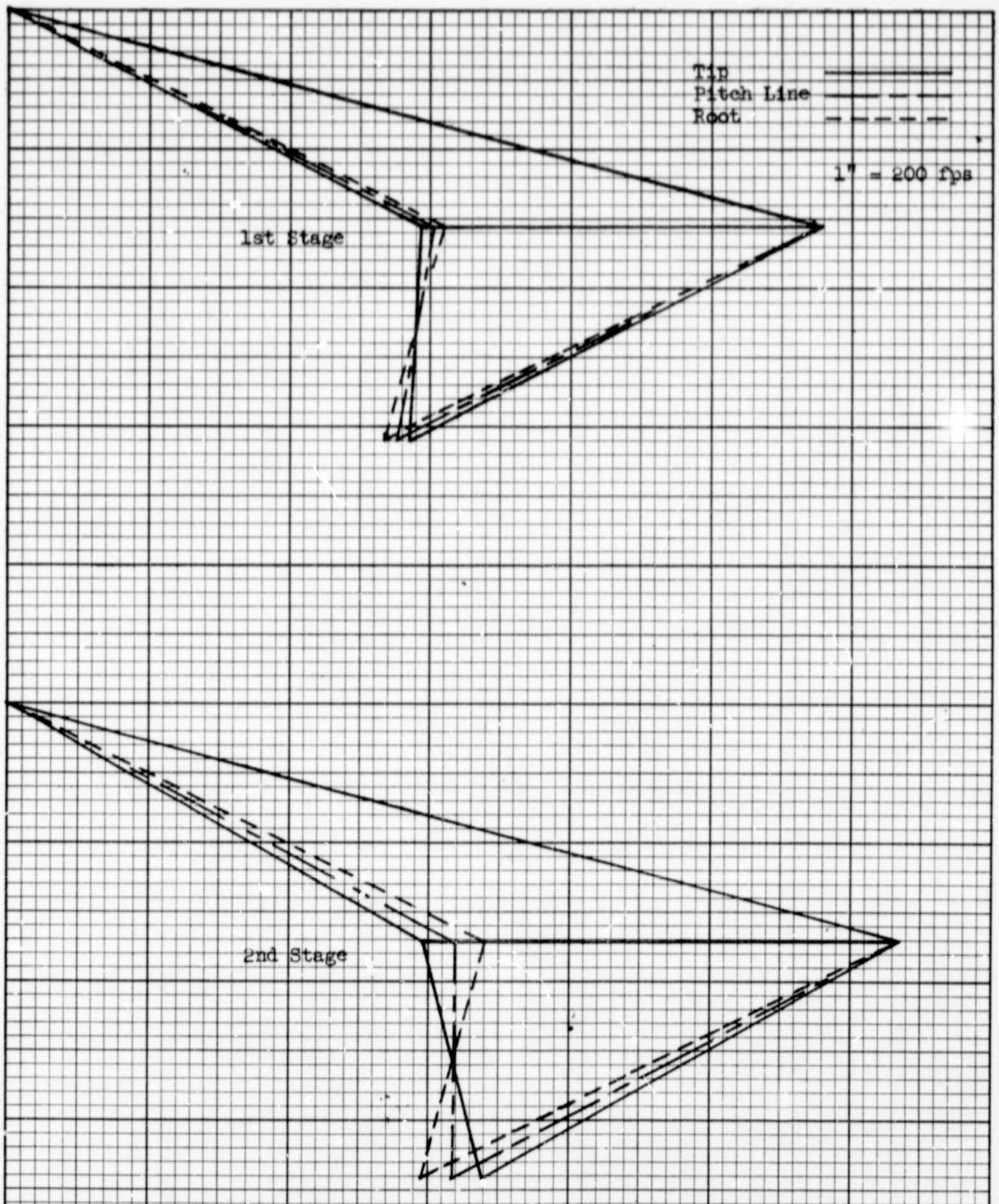


Fig. 32. Velocity Diagrams for the Two-Stage Rotor for the Cesium Turbine of Table 22 and Fig. 21.

ORNL DWG. 68-12604

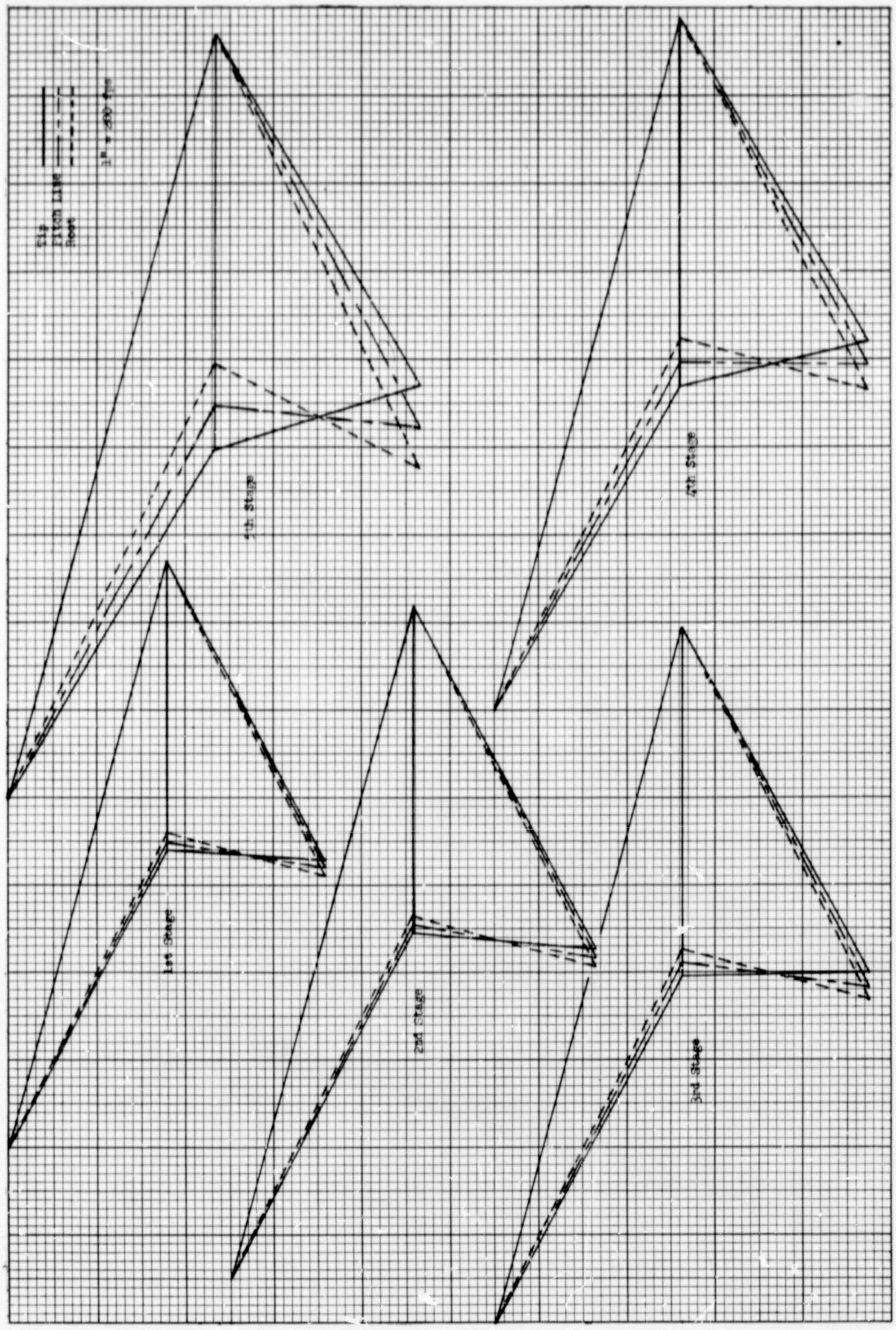


Fig. 33. Velocity Diagrams for the Five-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 25.

ORNL DWG. 68-12605

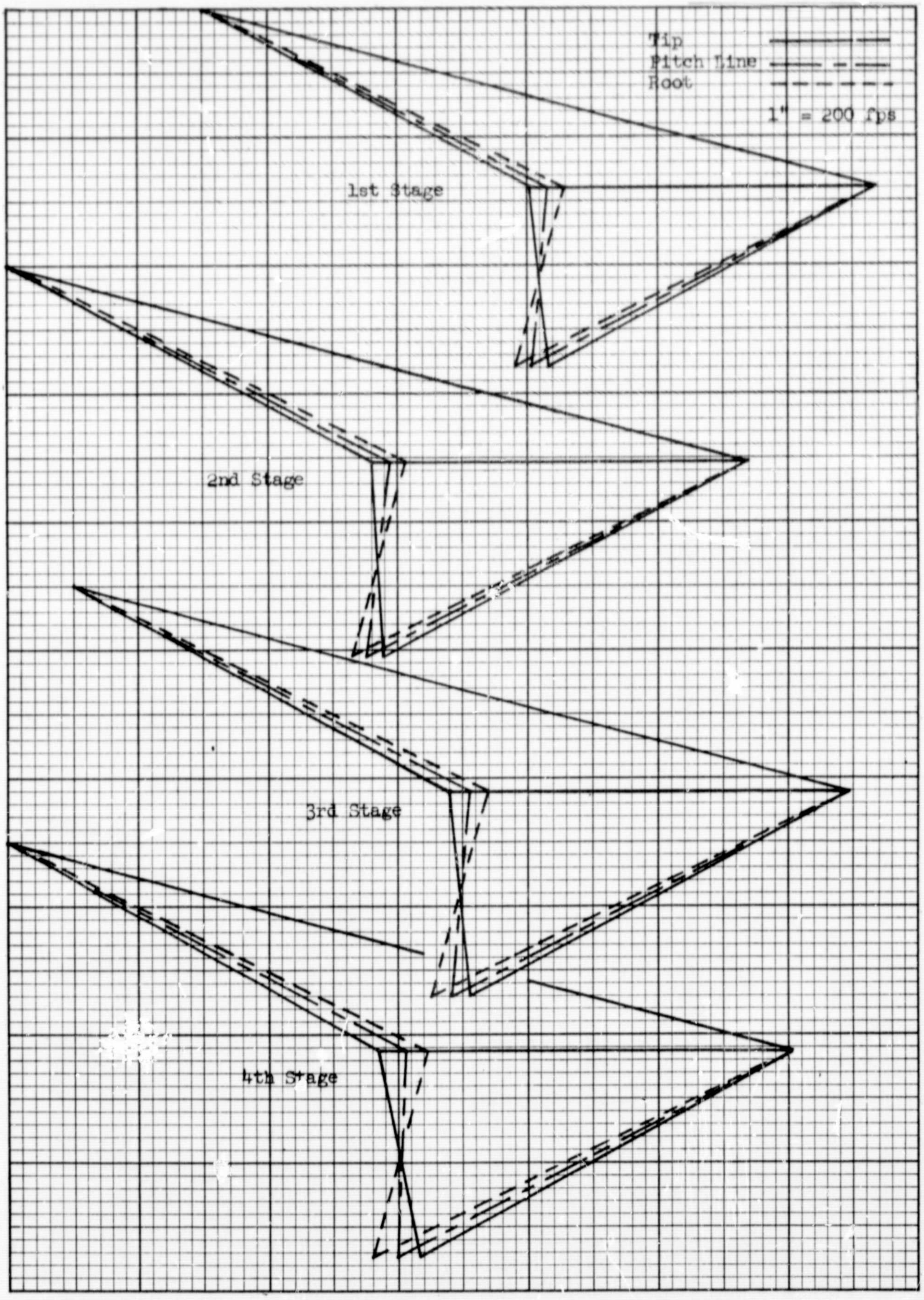


Fig. 34a. Velocity Diagrams of Stages 1, 2, 3, and 4 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

ORNL DWG. 68-12606

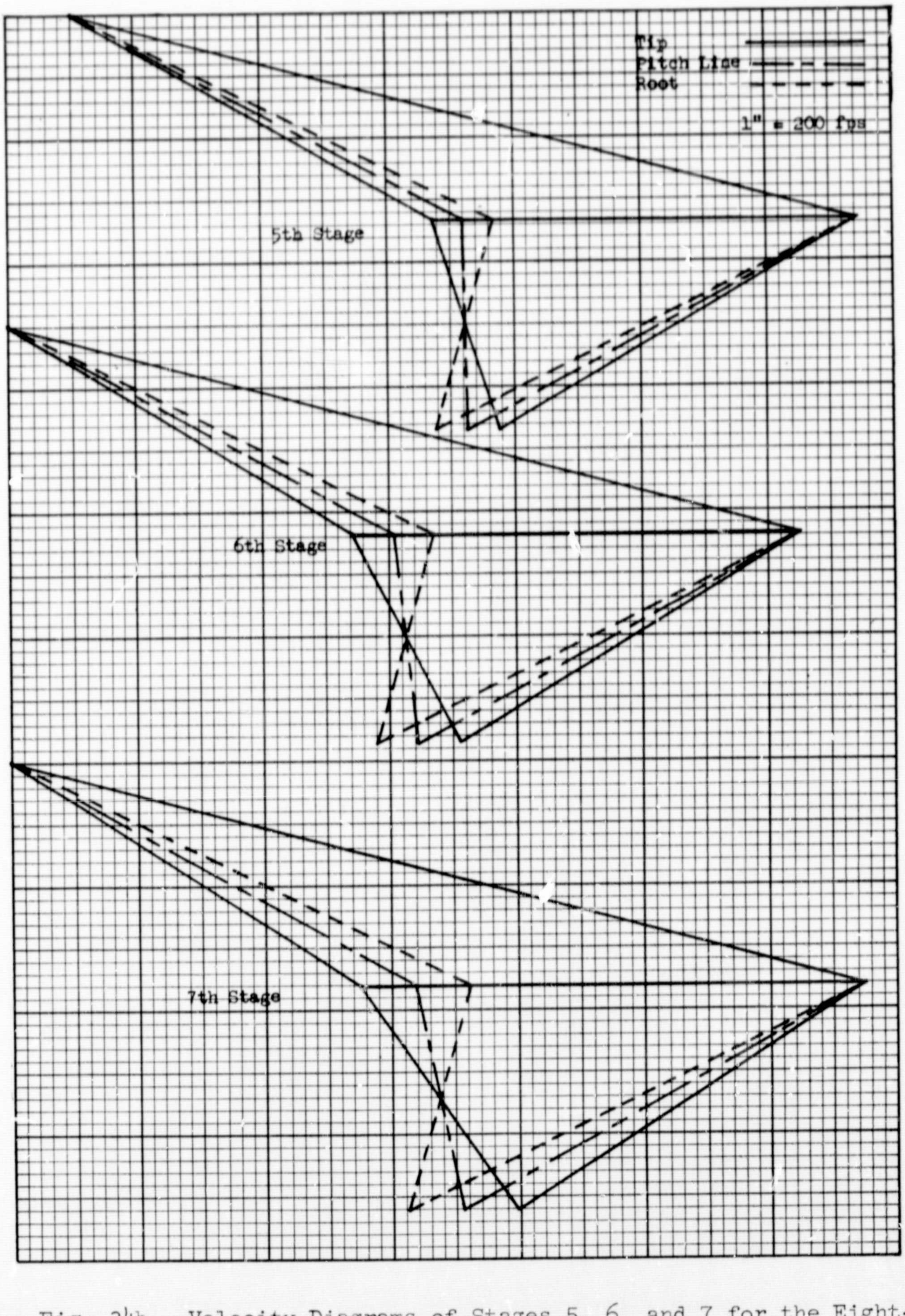


Fig. 34b. Velocity Diagrams of Stages 5, 6, and 7 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

ORNL DWG. 68-12607

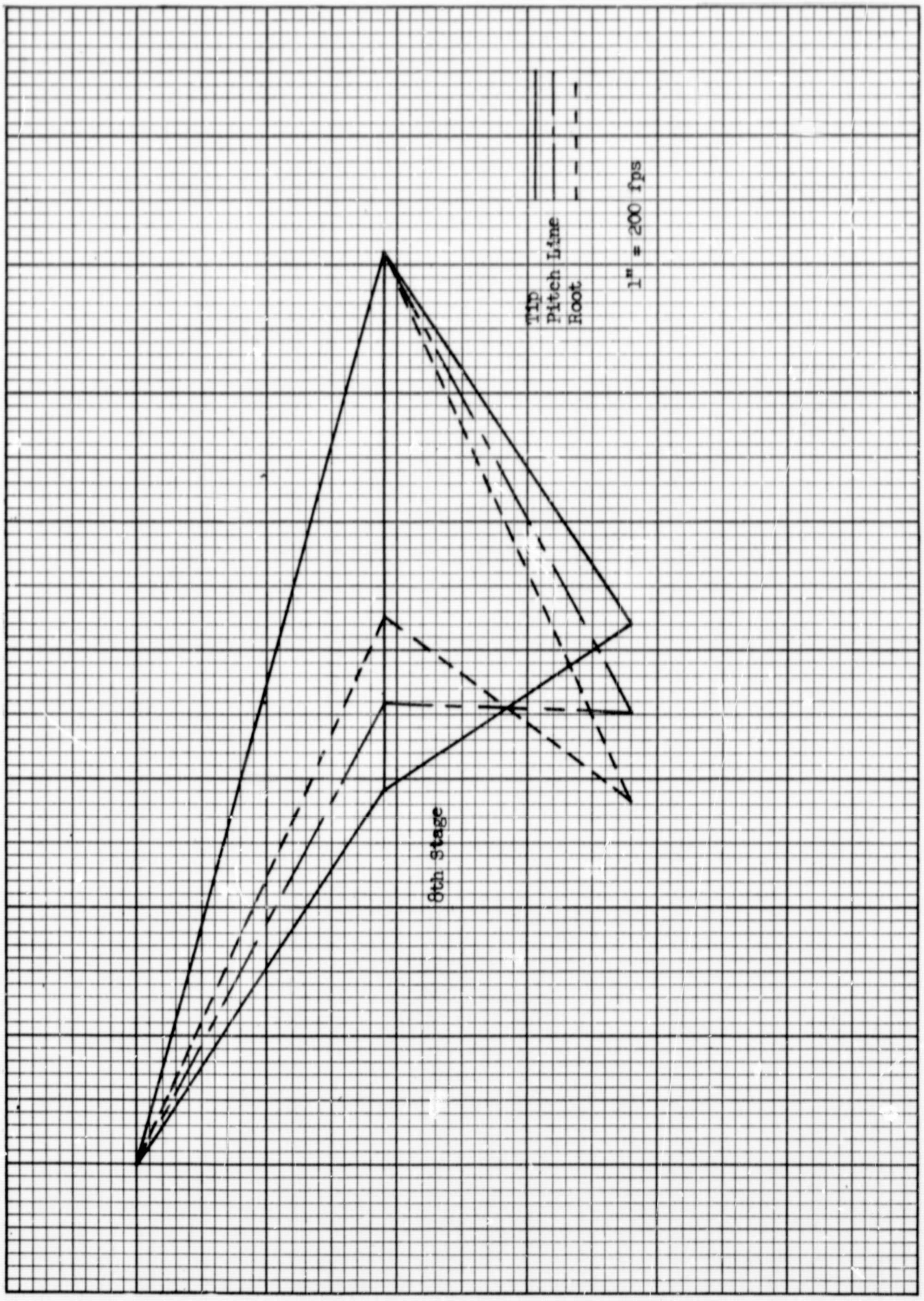


Fig. 34c. Velocity Diagram of Stage 8 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

ORNL DWG. 68-12608

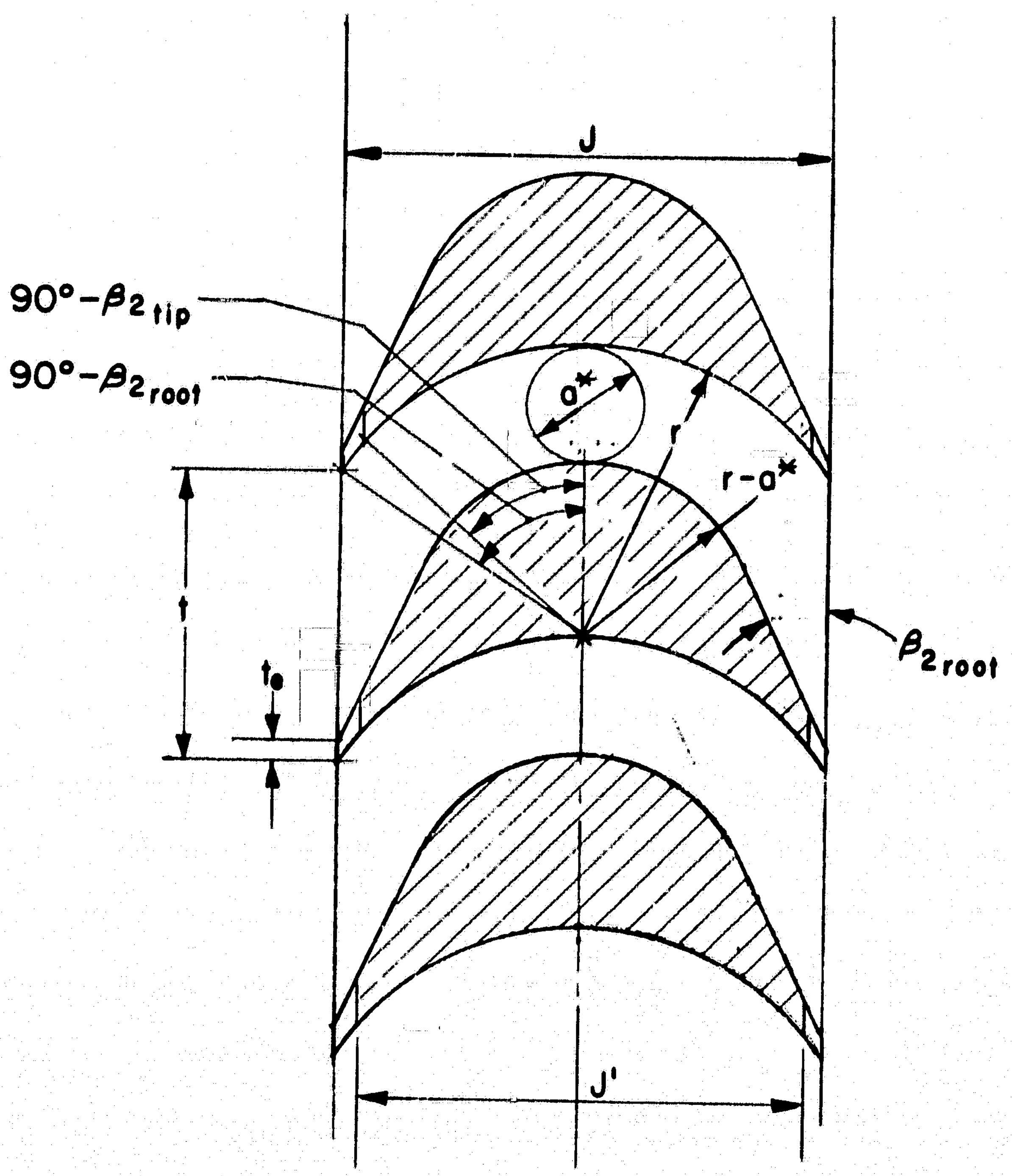


Fig. 35. Typical Row of Rotor Blades.

ORNL DWG. 68-12609

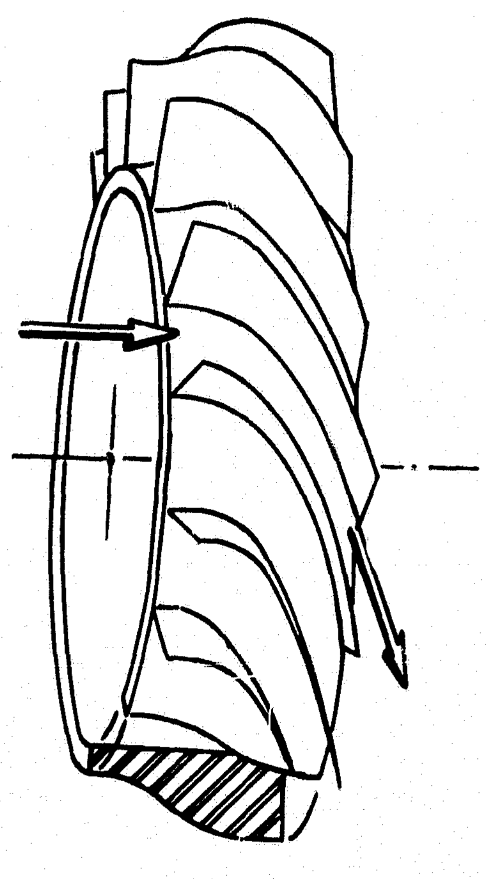


Fig. 36. Typical Row of Stator Blades.

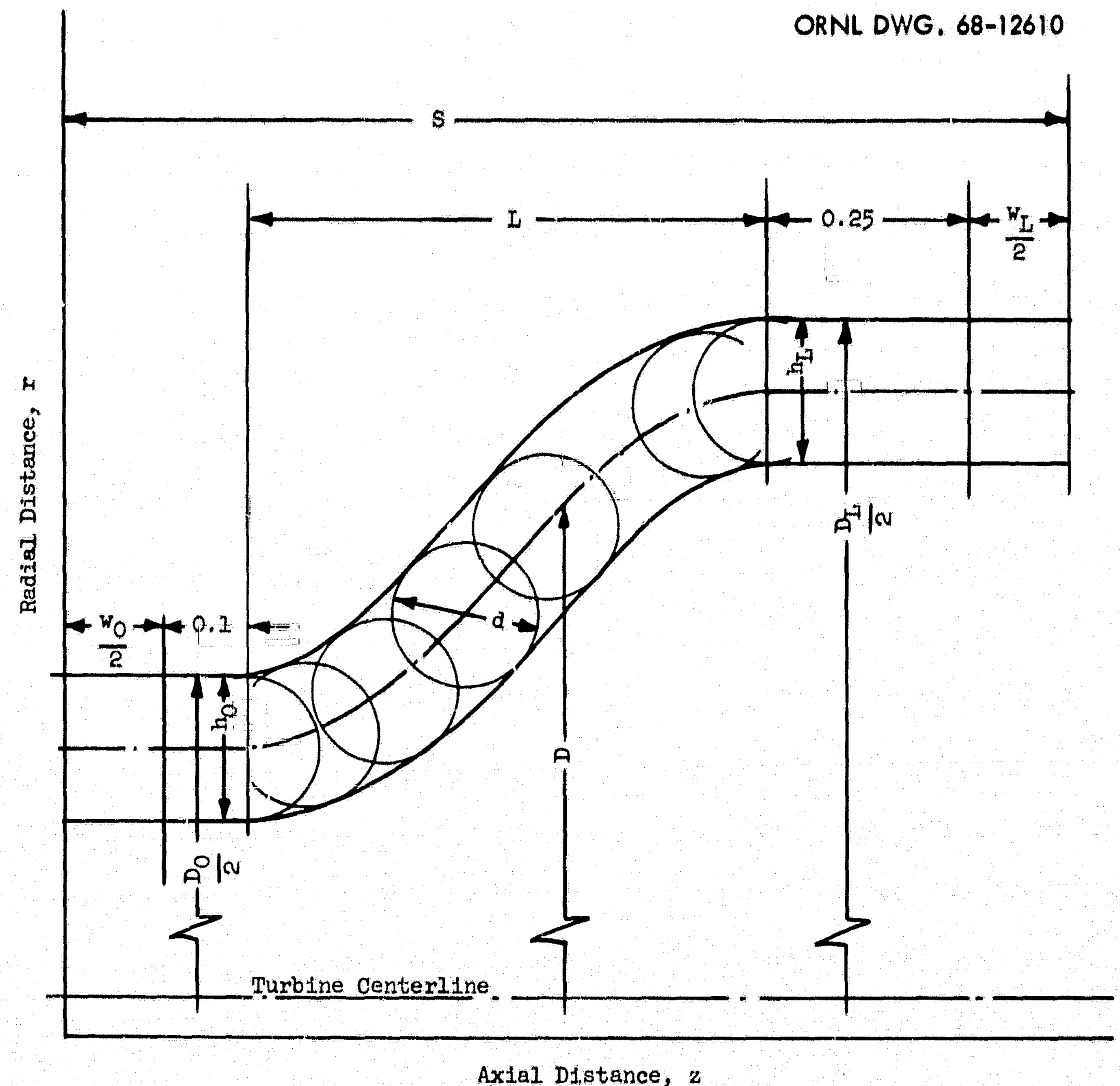


Fig. 37. Circumferential Projection of Stator Passage Onto a Radial Plane Through the Turbine Centerline.

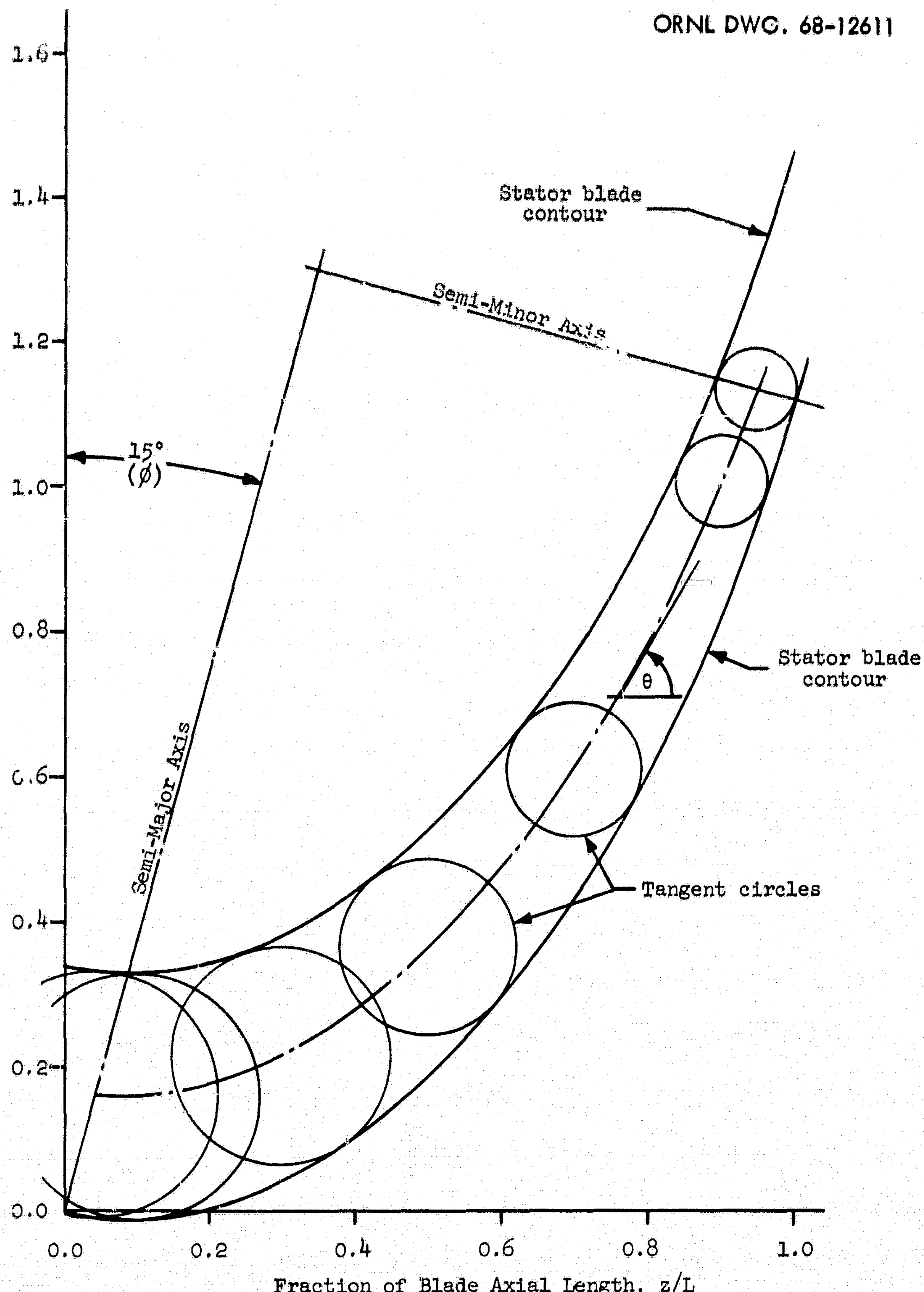


Fig. 38. Radial Projection of Stator Passage Onto a Constant Radius Circular Cylinder Concentric With the Turbine Centerline.

ORNL DWG. 68-12612

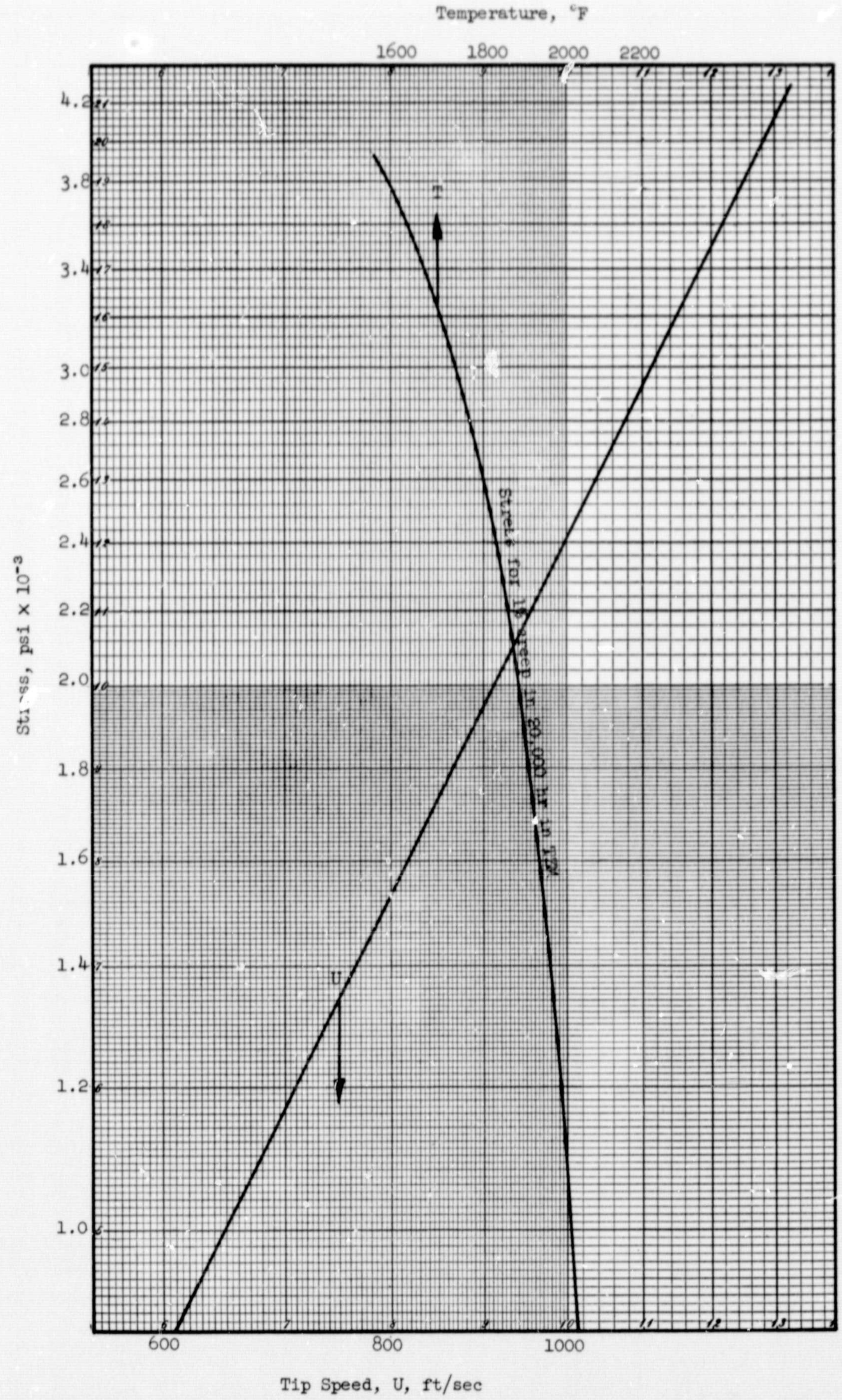


Fig. 39. Preliminary Estimates of the Stress in a Typical Turbine Rotor as a Function of Tip Speed and of the Effects of Temperature on the Stress in TZM Alloy for a Creep Rate of 0.5% per 10,000 hr.

ORNL DWG. 68-12613

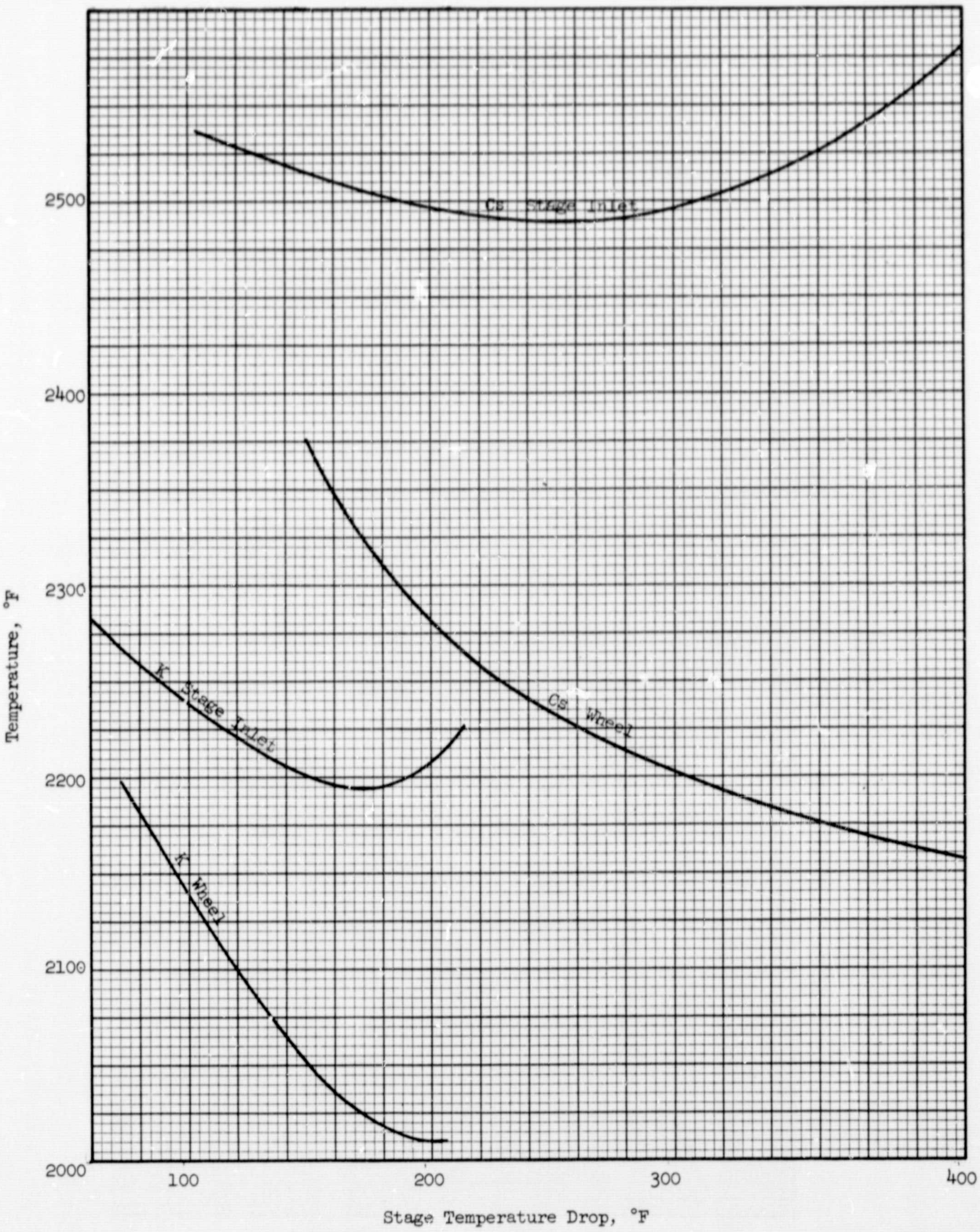
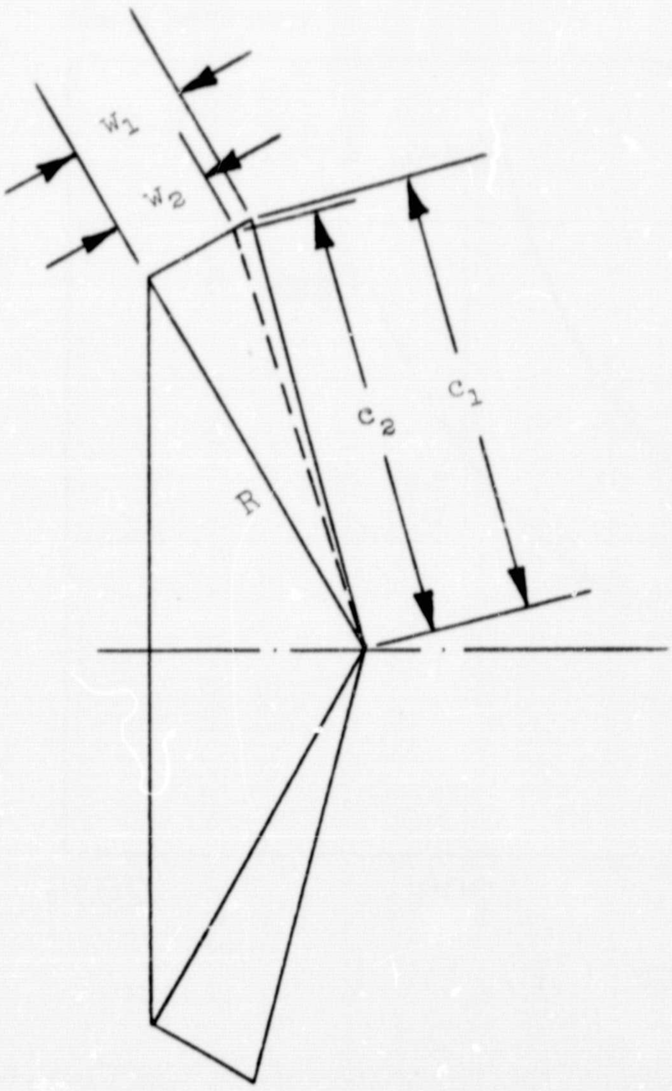


Fig. 40. Effects of First Stage Temperature Drop (or pressure ratio) on the Turbine Inlet Temperature Permitted by Creep Limitations in the First Stage Rotor.

ORNL DWG. 68-12614



From the Pythagorean Theorem:

$$R^2 + w_1^2 = c_1^2$$

$$R^2 + w_2^2 = c_2^2$$

Subtracting:

$$w_1^2 - w_2^2 = c_1^2 - c_2^2$$

$$(w_1 - w_2)(w_1 + w_2) = (c_1 - c_2)(c_1 + c_2)$$

For small differences:

$$w_1 + w_2 = 2\,w_1 \;;\; c_1 + c_2 = 2\,c_1$$

Substituting:

$$(w_1 - w_2)\,2\,w_1 = (c_1 - c_2)\,2\,c_1$$

$$\therefore\ c_1 - c_2 = (w_1 - w_2)\,\frac{w_1}{c_1}$$

Fig. 41. Geometry of Conical Centering Surfaces.

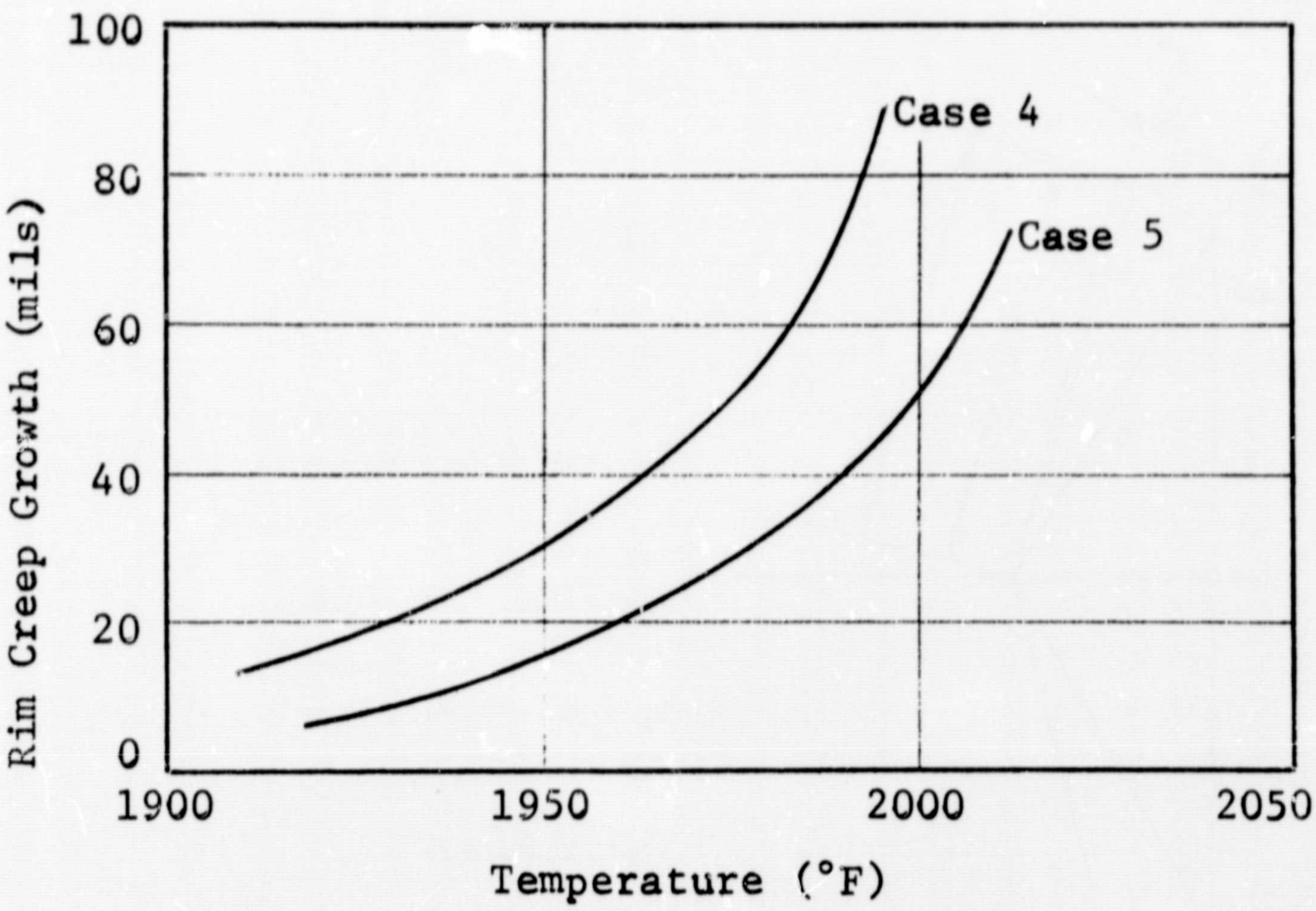


Fig. 42. Effects of Turbine Wheel Operating Temperature on the Growth of the Wheel for 40,000 hr of Operation as Estimated by MTI. (Curve excerpted from Ref. 21)

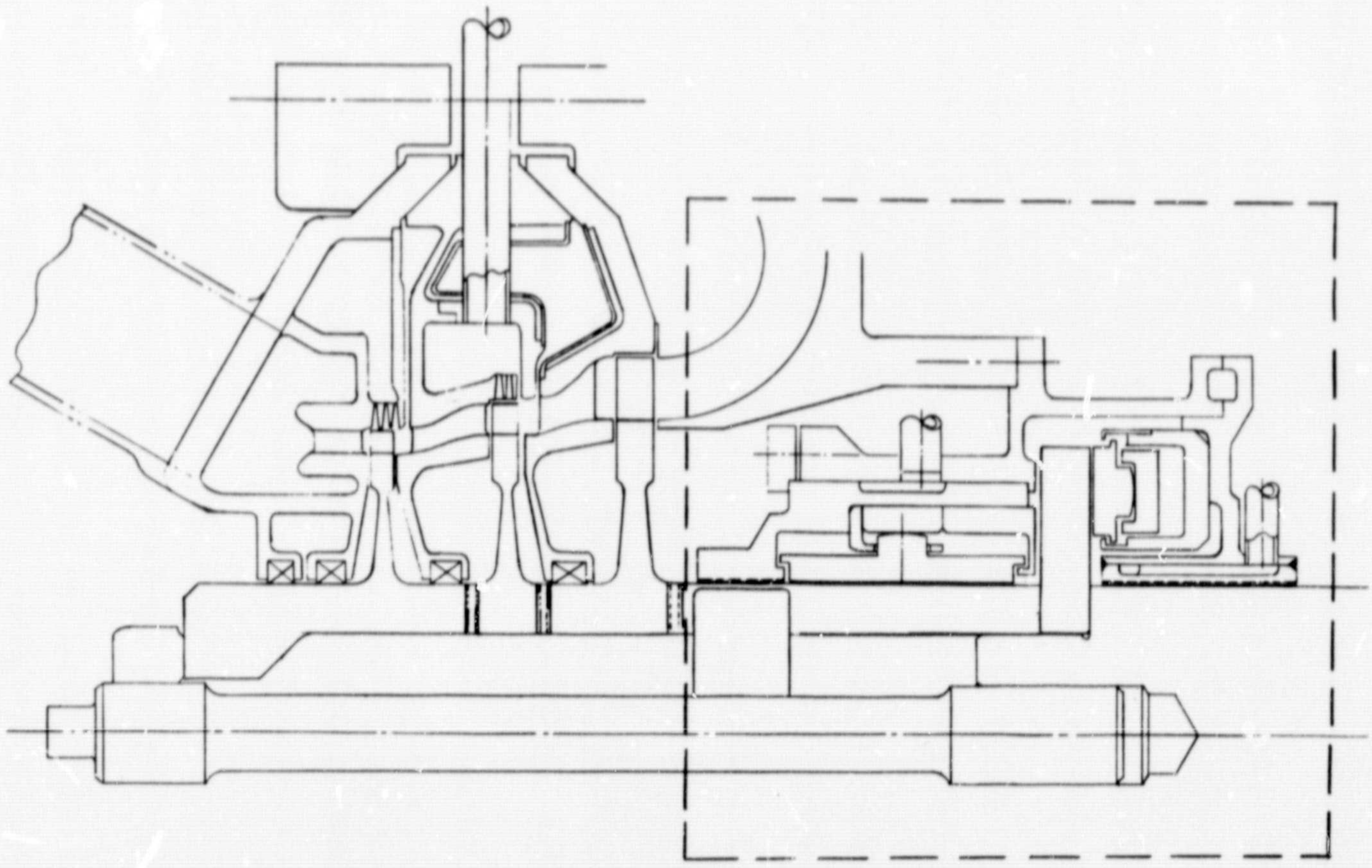


Fig. 43. Bearing Layout Evolved by MTI for the Two-Bearing Turbine-Generator Reference Design Units. (Drawing excerpted from Ref. 21)

ORNL DWG. 68-9397

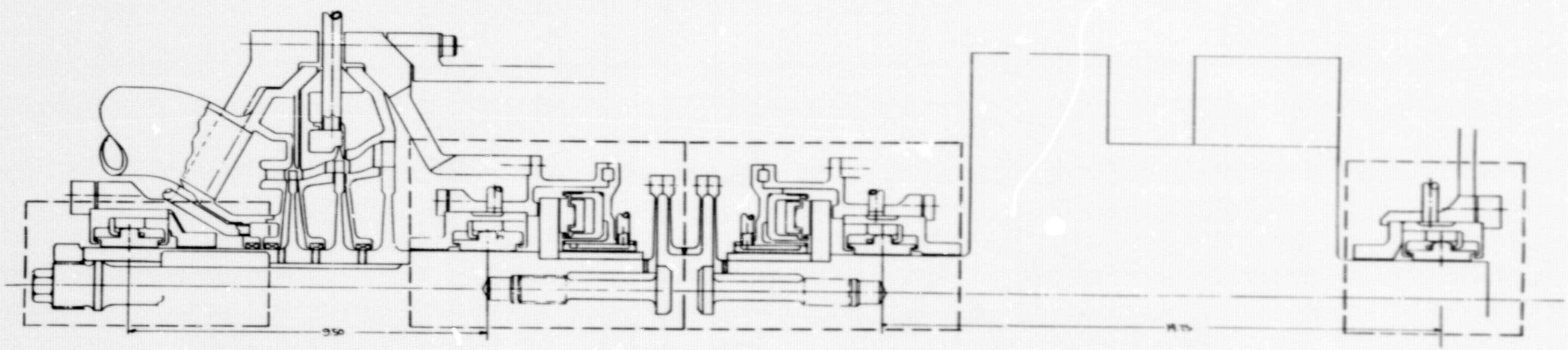


Fig. 44. Bearing Layout Evolved by MTI for the Four-Bearing Turbine-Generator Reference Design Units. (Drawing excerpted from Ref. 21)

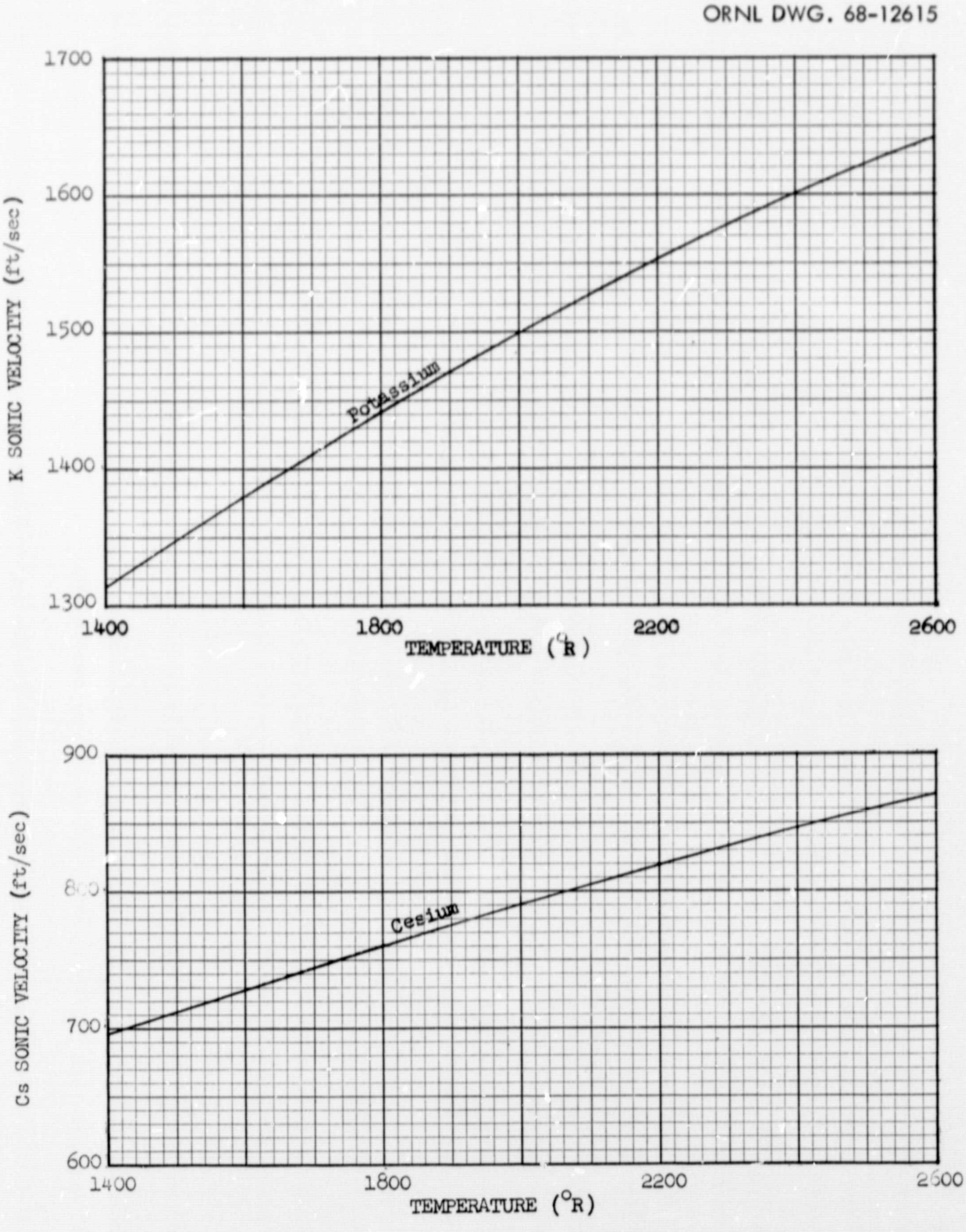
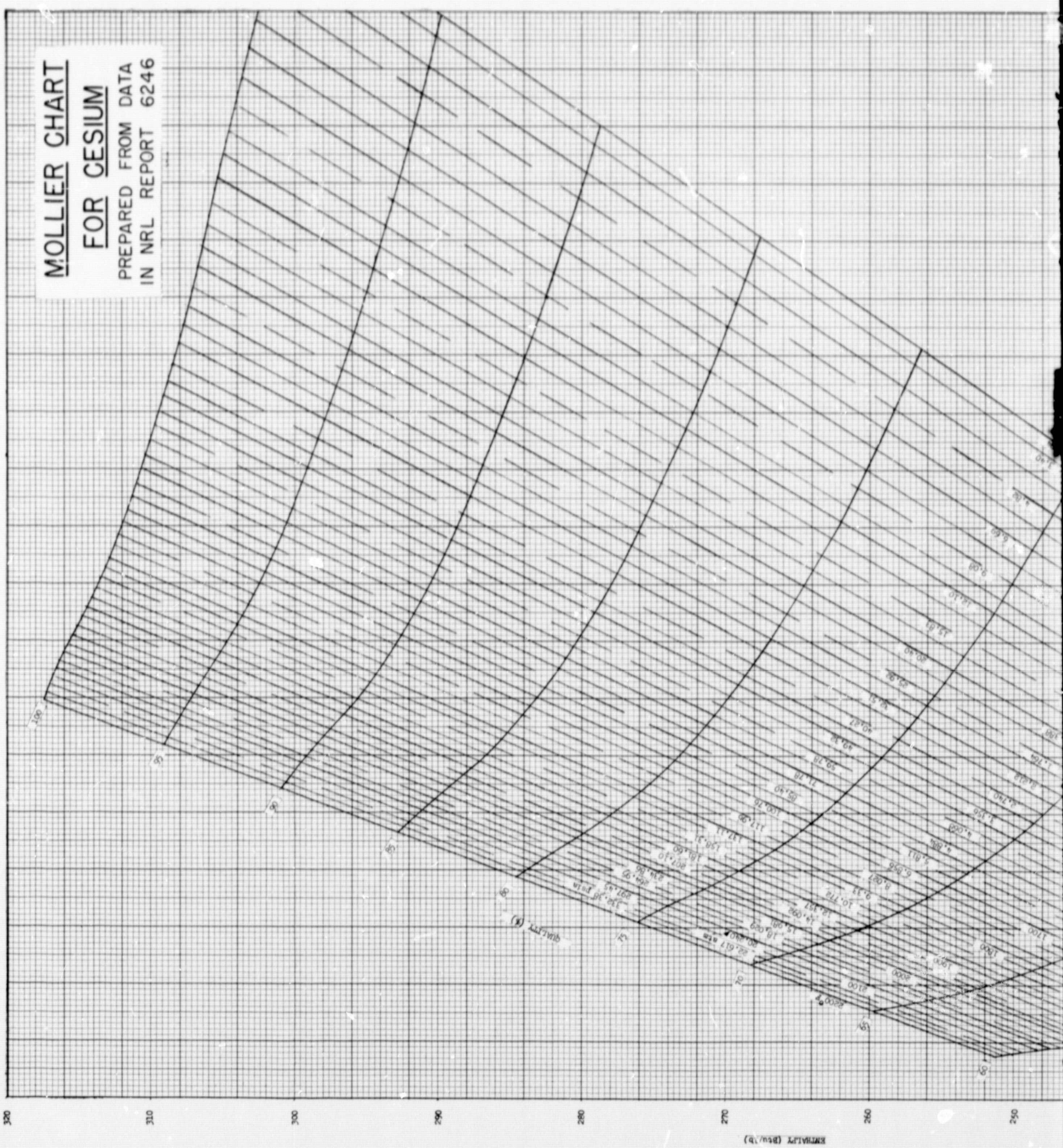


Fig. 45. Sonic Velocities in Cesium and Potassium Vapor as Functions of Temperature (based on equilibrium conditions). (Data from Ref. 19)

FOLDOUT FRAME 1



FOLDOUT FRAME 2

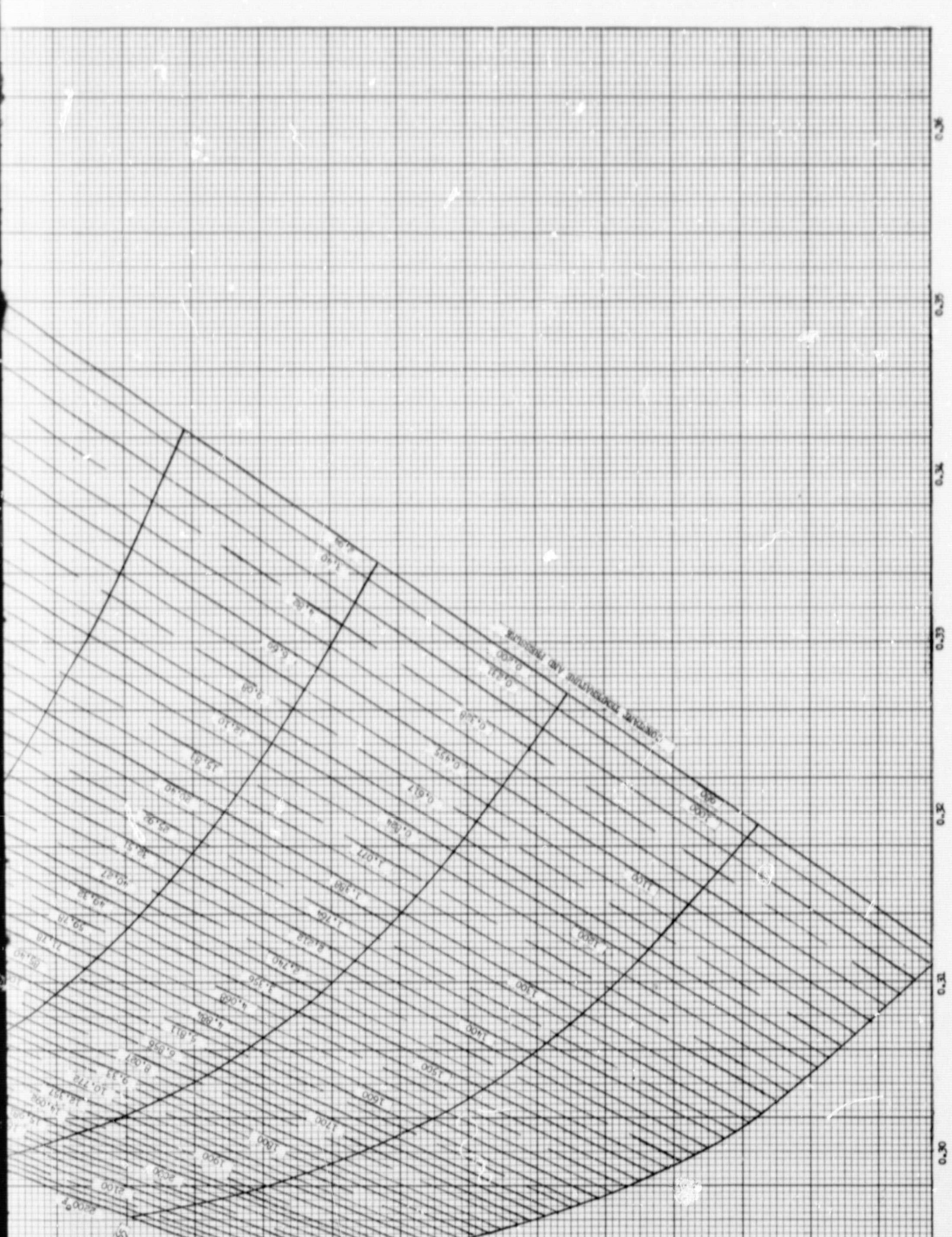


Fig. 46. Mollier Diagram for Cesium. (Data from Ref. 19)